AUTOMATIC FREQUENCY TRACKING AND AN APPLICATION OF TARGET TRACKING USING PASSIVE DOPPLER TECHNIQUES

Dennis Wayne Hurst

NAVAL POSTGRADUATE SCHOOL
Monterey, California

THESIS

AUTOMATIC FREQUENCY TRACKING AND
AN APPLICATION OF TARGET FIXING
USING PASSIVE DOPPLER TECHNIQUES

by

Dennis Wayne Hurst

September 1974

Thesis Advisor: H. A. Titus

Approved for public release; distribution unlimited.

Unclassified

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE

READ INSTRUCTIONS BEFORE COMPLETING FORM

1. REPORT NUMBER

2. GOVT ACCESSION NO.

3. RECIPIENT'S CATALOG NUMBER

4. TITLE (and Subtitle)
Automatic Frequency Tracking and An Application of Target Fixing Using Passive Doppler Techniques

5. TYPE OF REPORT & PERIOD COVERED
Master's Thesis; Sept 1974

6. PERFORMING ORG. REPORT NUMBER

7. AUTHOR(s)
Dennis Wayne Hurst

8. CONTRACT OR GRANT NUMBER(s)

9. PERFORMING ORGANIZATION NAME AND ADDRESS
Naval Postgraduate School
Monterey, California 93940

10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS

11. CONTROLLING OFFICE NAME AND ADDRESS
Naval Postgraduate School
Monterey, California 93940

12. REPORT DATE
September 1974

13. NUMBER OF PAGES

14. MONITORING AGENCY NAME & ADDRESS(if different from Controlling Office)

15. SECURITY CLASS. (of this report)
Unclassified

15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)
Approved for public release; distribution unlimited.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)
A software package was developed to provide the inputs for a passive single-sensor acoustic tracker. This required a computation of sound propagation velocity and resolving high-resolution frequency information from raw acoustic data. A selected frequency was then automatically tracked from an up-doppler to a down-doppler condition. This frequency information coupled with associated bearing information was then used to provide continuous target fixes.

Automatic Frequency Tracking and an
Application of Target Tracking
Using Passive Doppler Techniques

by

Dennis Wayne Hurst
Lieutenant, United States Navy
B.E.E., Auburn University, 1967

Submitted in partial fulfillment of the
requirements for the degree of

MASTER OF SCIENCE IN ENGINEERING ACOUSTICS

from the

NAVAL POSTGRADUATE SCHOOL
September 1974

ABSTRACT

A software package was developed to provide the inputs for a passive single-sensor acoustic tracker. This required a computation of sound propagation velocity and resolving high-resolution frequency information from raw acoustic data. A selected frequency was then automatically tracked from an up-doppler to a down-doppler condition. This frequency information coupled with associated bearing information was then used to provide continuous target fixes.

TABLE OF CONTENTS

LIST OF TABLES

TABLE

LIST OF FIGURES

FIGURE

FIGURE

I. INTRODUCTION

Continuous fixing of an underwater sound source by passive means has traditionally been carried out by using multiple sensors. Single sensor fixing requires varying power coefficients, frequencies, and/or bearing changes and usually produces an estimated position with an accuracy that varies greatly with the type of sensor and processing utilized and the skill of the evaluator. An accurate single sensor track would be advantageous in that positional errors could be minimized with only one buoy or array required, providing greater flexibility in that a series of sensors are not required to be monitored, and a decrease in buoy expenditures could be expected. To provide the necessary frequency data, a software package was developed that computed the sound propagation velocity, detected a discrete frequency signal and automatically tracked that signal from a full up-doppler through a full down-doppler situation. This frequency output combined with associated bearing information, and a value for the sound propagation speed with an estimate of the speed of the target provides sufficient input data for single sensor fixing.

II. THE TRACKING PROBLEM

A. STATEMENT OF THE PROBLEM

Chapter 3 of [1] developes the required input quantities for passive, single-sensor fixing. These values are an estimate of target speed, the velocity of sound propagation in the medium, the doppler shifted frequency and a bearing from the sensor to the target. The estimate of target speed would have to be determined by tactical considerations at the time and location of signal acquisition, i. e., target transiting or on-station, signal strength, detection ranges, etc. The bearing would be provided by a standard DIFAR buoy or an array. In this problem the standard deviation of bearing measurement noise was varied from 5^{o} to 30^{o}. Methods of providing the sound propagation velocity and the doppler shifted frequency were then devised.

B. DEVELOPING THE INPUTS

Equation 1. 1. of [2] provides a good approximation of sound speed in sea water as a function of temperature, salinity and pressure. It is repeated here as equation 1.

$$c(T,S,z)=1449+4.62T-.054T^{2}+1.3(S-35)+.017z \qquad (1)$$

where c is in meters per second, T is in degrees centigrade, S is in parts per thousand, and z is in meters. Converting this equation so that c is in yards per second, T is in degrees Farenheit and depth is in feet, yields equation 2.

$$c(T,S,z)=1476.1+3.97T-.018T^2+1.42(S-35)+.0057z \tag{2}$$

If the target depth is known, the median depth of the target and hydrophone should be used. Otherwise, use the hydrophone depth. Salinity would normally be set to 35ppt unless operating in water of a known different salinity. The resultant output from this equation would be set equal to the velocity of sound propagation, VP, and used as an input value to the target tracker program.

The frequency requirements called for a high-resolution value which dictated a relatively long time window. A twenty second window was used which resulted in a .05Hz FFT resolution. This resolution was further enhanced by interpolation using the relative values of the power coefficients associated with the discrete frequency being tracked. In order to maintain contact on the same discrete frequency line, a frequency tracker algorithm was devised. This provided the necessary frequency data for the target tracker program.

III. SOFTWARE IMPLEMENTATION

A. SOUND SPEED

This process was a simple matter of implementing the equation for sound speed in seawater, equation 2. Providing the chosen depth, observed temperature, and salinity results in a best estimate of the actual sound speed in the operating area. Updating this value would be necessary as the operating area or environmental conditions changed.

B. FREQUENCY

1. Parameters for Frequency Computations

In order to provide realistic frequency inputs, a magnetic tape was obtained that contained analog, raw acoustic signals representing ambient noise plus an underwater sound emitter with various discrete frequencies. The doppler shift of a discrete frequency signal is directly proportional to the rest frequency of the signal. Thus doppler shift measurements are more easily obtained from higher frequencies. However, signal attenuation in the medium is much higher at higher frequencies. At present, frequencies in the 150Hz to 300Hz range will yield usable values with realizable frequency resolution measurements. The highest signal frequency of interest determines the required sampling rate of the data. The sampling rate and the time window length determine the required dimension of the data input matrix. With these

considerations in mind, the following parameters were chosen in digitizing the data:

Sampling Rate of 512 samples/second yields Nyquist frequency of 256Hz;
Input data low-pass filtered to 250Hz to prevent aliasing errors;
Time record length of 20 seconds for FFT resolution of .05 Hz/Bin;
Hanning window function applied in time domain to reduce sidelobes associated with rectangular data windows.

2. Power Spectrum

With the above chosen data parameters, the input matrix to the POWER Subroutine* [3] was dimensioned to 20,480 bins. This corresponds to two bins per data point (1 cosine term and 1 sine term for 10,240 data points) or 10,240 Complex Fourier coefficients. The real data values were loaded into the odd (cosine or real) bins and zero's were provided for the even (sine or imaginary) bins. On return from the FFT Subroutine [6] to the POWER Subroutine, the cosine term is squared and added to its associated sine term squared thus representing the power at some discrete frequency. This discrete frequency is an integer multiple of the FFT processing resolution (the reciprocal of the time record length). The first bin, Y(1), contains the zero frequency power coefficient, the second bin contains the .05 Hz power coefficient, and so on in .05 Hz steps. Thus bins Y(1) through Y(5001) now contained the power coefficients from zero to 250 Hz.

---

*Subroutine STATS and POWER were written by Arfman, J. F., Jr., and were adapted for use in this program.

3. Search Window and Background Noise Suppression

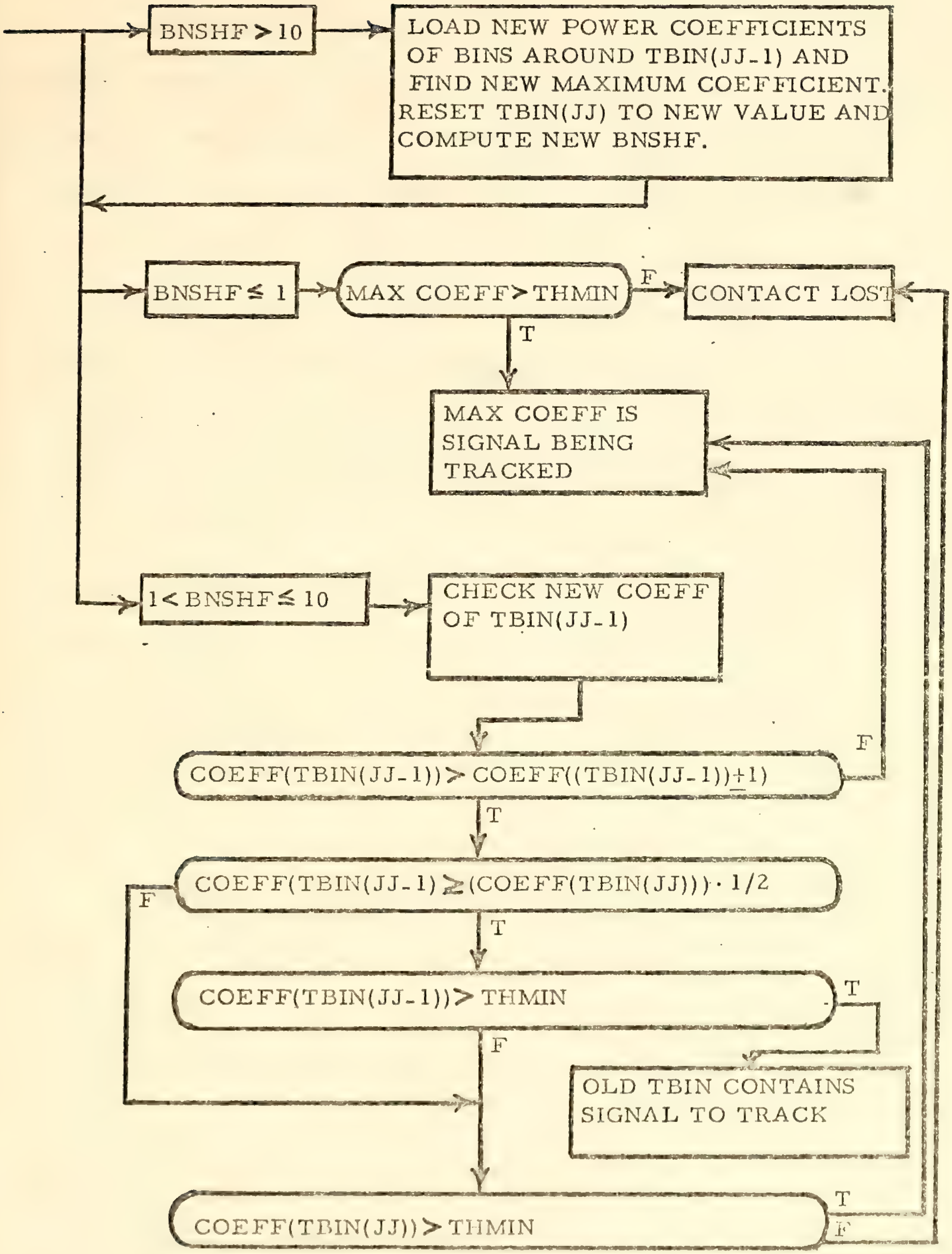
With over five thousand power coefficients available for tracking, it is convenient to limit the range of search to those that offer the best data for doppler tracking. A signal having favorable characteristics is first identified, i. e., frequency above 100 to 150 Hz, apparently stable on a one Hz resolution processor, and of sufficient strength to maintain a favorable signal-to-noise ratio for a majority of the time. Then a search window is designated by the adjustable parameters FL and SRBW, where FL is the lower frequency limit of the search window and SRBW is the search window bandwidth. Both parameters must be some integer multiple of the FFT resolution and would usually be kept at whole numbers for convenience. The total number of power coefficients in the search window would equal N=20(SRBW) and are designated YA(1) to YA(N).

Ideally when the frequency to be tracked (FTRK) has been identified, FL and SRBW should be chosen such that FTRK is equal to FL plus (1/2)SRBW and SRBW is as large as is reasonable to keep the ratio of signal power in the window to the total power in the window much less than one. If $\sum_{K=1}^{L} YA(K) \ll \sum_{J=1}^{M} YA(J)$ for L signal bins and M noise bins with L+M=N, then the summation as I goes from one to N of YA(I)/N is a reasonable approximation of the ambient noise level around FTRK [4], [5]. This calculation is performed and set equal to YNOIS. Then YNOIS, or some function of it dependent on the signal-to-noise ratio, is subtracted from each power coefficient in the search window. Under the

assumption that the noise power spectrum is constant (white noise) within SRBW, only the signal power spectrum remains in the window.

4. Frequency Tracking to Follow the Doppler Shift

The frequency selected to be tracked will be the strongest signal in the search window when the first transform is computed. The bin number of that signal is saved as TBIN(JJ). In each succeeding transform the strongest signal (largest coefficient) in the search window is designated TBIN(JJ) and is compared to TBIN(JJ-1). A bin shift greater than 10 is determined to be a new or different discrete signal. The new power coefficients around the last center bin are then examined for discrete signal energy. The maximum value found would be considered the signal energy being tracked if its bin number is equal to the last center bin number plus or minus 1, and its magnitude is greater than a chosen threshold minimum. In this problem this value was set to three times the ambient noise value. If the maximum coefficient found is more than one bin from the last center bin, the old center bin is examined. If its coefficient is larger than at least one of its sidelobe bin values and at least half as large as the maximum found and larger than the chosen threshold minimum value, the old signal bin is considered to still contain the signal being tracked. If any of these test fail, the new maximum found is compared to the chosen minimum value. If the new maximum is larger, it is accepted as the signal being tracked; if not the contact is considered lost. Figure 1 possibly clarifies the above process.



BIN SHIFT = BNSHF = TBIN(JJ) − TBIN(JJ-1)

THMIN = A CHOSEN THRESHOLD MINIMUM VALUE

FIGURE 1. FREQUENCY TRACKER DECISION FLOW.

Once the bin containing the largest portion of the signal energy being tracked has been established, the frequency of that signal is refined by computing the first moment of the three bin power "hump" around it. If the detected signal is an integer multiple of the FFT resolution, adjacent bin spill over will be minimum and the refining calculation would make no correction to the frequency of the bin associated with the maximum power. When the detected signal is not an integer multiple of the FFT resolution the refining calculation adjusts the frequency to a mid-resolution value corresponding to the first moment of the hump. See Figure 2. The frequency corresponding to bin number K is stored in the YL matrix as YL(K). The frequency refining equation used was

FTRK(JJ)=YL(K)+RESOL*(YA(K+1)-YA(K-1))/(YA(K+1)
+YA(K)+YA(K-1)) (3)

where

FTRK=the discrete frequency being tracked,

RESOL=the resolution of the FFT processing,

YA(M)=the power coefficient of the Mth bin.

Letting YL(K)=220.25Hz and using the sample values from figure 2,

$$\begin{aligned}
\text{FTRK(JJ)} &= 220.250\text{Hz} + .05\text{Hz} \cdot \left(\frac{1 - 4}{1 + 7 + 4} \right) \\
&= 220.250\text{Hz} + .05\text{Hz} \cdot (-.25) \\
&= 220.250\text{Hz} - .0125\text{Hz} \\
&= 220.2375\text{Hz} \\
& \quad 220.238\text{Hz (rounded)}
\end{aligned}$$

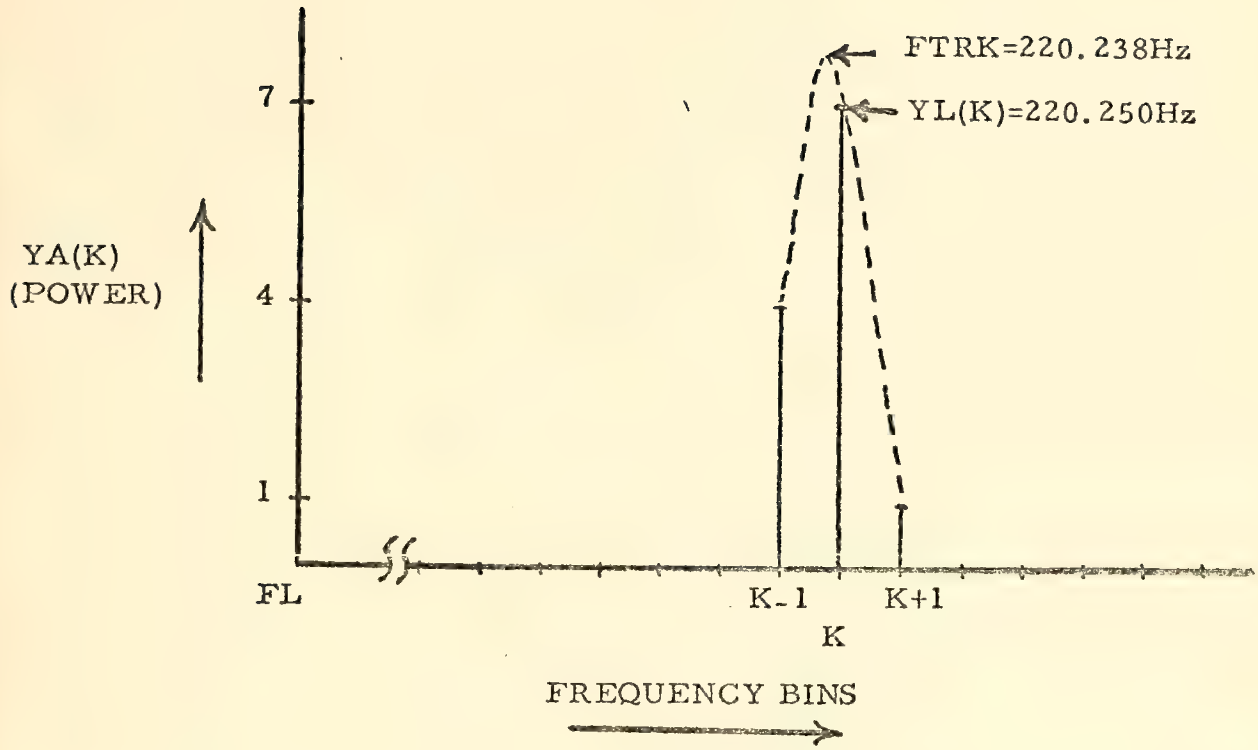


FIGURE 2. RESOLVING MID-RESOLUTION FREQUENCIES WHEN THE DETECTED SIGNAL IS NOT AN INTEGER MULTIPLE OF THE FFT RESOLUTION.

Without this calculation the returned value of the frequency being tracked would have been 220.250Hz. A five bin computation was found to offer no significant improvement over the three bin computation due to the increased probability of noise or adjacent discrete signal influence.

C. DESIGNATING PROBLEM VALUES

In computing the sound propagation speed for the following examples, nominal values were used because the true values were not available. Values used were:

Temperature = $48^{\circ}F$

Depth = 60 ft

Salinity = 35 ppt

The sound emitter on the data tape appeared to make a slow turn into the buoy for the first 4 minutes of the tape and then maintain a constant course at a speed of approximately 4.5 knots. The closest-point-of-approach (CPA) to the hydrophone was approximately 300 to 700 yards and 20 minutes of data was utilized with CPA at about the 11 to 12 minute point on the tape. A 20 Hz search window bandwidth was used with several different lower frequency limits on the window. It was found that one transform per minute comfortably contained the tracked frequencies within the 21 bin tracking window in all cases for a slow-moving, near-field emitter.

D. DATA OUTPUT

1. Run 1 (See Table 1)

With FL set to 40 Hz and SRBW at 20 Hz, the rest frequency of the tracked signal was approximately 50. 13 Hz. The total doppler shift was only 0. 15 Hz and was too low to provide good tracking data.

2. Run 2 (See Table 2)

For this run FL was set to 220 Hz with SRBW still at 20 Hz. Two strong discrete frequency signals were within the search window bandwidth, one's rest frequency at 233. 87 Hz and the other at 223. 22Hz. The maximum power coefficient changed between these two signals several times. In the initial transform the tracker locked on to the lower of the two frequencies and a continuous track was maintained even though the signal faded out and then came back. This run gave the frequency tracker a good check-out in that (a) the maximum coefficient in the search window had considerable variations between discrete signals (b) a noise spike occurred in the tracker window at time=430 (FILE=220) and (c) the tracked signal faded completely out at time=1090 (FILE=550) and was regained one minute later. The total doppler shift was approximately 0. 6 Hz and provided good data for doppler tracking. The computer output for this run is included in this report in its entirety.

3. Run 3 (See Table 3)

For this run FL was set to 225 Hz and SRBW remained at 20 Hz. The only significant signal in the search window was the 233. 87 Hz signal

Time (seconds)	Center Bin	Ratio: Signal/Noise	Frequency Tracked
10.0	204	155/66	50.155
70.0	205	1759/38	50.190
130.0	205	1619/59	50.185
190.0	205	2001/54	50.203
250.0	205	1620/39	50.180
310.0	205	1527/49	50.192
370.0	204	878/40	50.197
430.0	205	247/42	50.151
490.0	205	9320/78	50.178
550.0	205	13280/68	50.191
610.0	204	56746/254	50.168
670.0	203	38878/144	50.105
730.0	203	42170/187	50.085
790.0	203	47640/227	50.081
850.0	202	6941/55	50.060
910.0	202	9654/71	50.063
970.0	202	18841/125	50.053
1030.0	202	17558/111	50.057
1090.0	202	17546/104	50.054
1150.0	202	14377/87	50.050

Rest Frequency approximately 50.13 Hz

TABLE I.
FREQUENCY TRACKER OUTPUT WITH FL= 50 Hz, SRBW=20 Hz.

Time (seconds)	Center Bin	Ratio: Signal/Noise	Frequency Tracked
10.0	70	69/6	223.437
70.0	71	112/5	223.481
130.0	71	61/5	223.495
190.0	72	52/5	223.556
250.0	71	254/6	223.489
310.0	70	218/6	223.473
370.0	69	490/9	223.420
430.0	69	64/8	223.407
490.0	70	743/24	223.434
550.0	71	2131/41	223.488
610.0	69	10429/68	223.396
670.0	62	4795/50	223.063
730.0	60	2554/26	222.960
790.0	61	2119/16	222.995
850.0	60	322/14	222.938
910.0	59	245/10	222.882
970.0	59	60/4	222.898
1030.0	59	112/6	222.886
1090.0	60	12/5	Lost Track
1150.0	59	115/5	222.901

Rest Frequency approximately 223.22 Hz

TABLE II.
FREQUENCY TRACKER OUTPUT WITH FL=220 Hz, SRBW=20 Hz.

Time (seconds)	Center Bin	Ratio: Signal/Noise	Frequency Tracked
10.0	183	61/4	234.100
70.0	184	42/4	234.151
130.0	185	21/4	234.193
190.0	185	77/5	234.224
250.0	184	167/5	234.169
310.0	184	160/5	234.163
370.0	183	829/7	234.102
430.0	184	708/8	234.144
490.0	184	3295/19	234.132
550.0	184	4824/32	234.130
610.0	183	4669/30	234.079
670.0	176	6049/29	233.756
730.0	174	906/13	233.644
790.0	174	766/7	233.634
850.0	172	1082/11	233.563
910.0	172	1020/8	233.558
970.0	172	27/4	233.563
1030.0	172	357/5	233.545
1090.0	172	135/5	233.530
1150.0	171	23/5	233.525

Rest Frequency approximately 233.87 Hz

TABLE III.
FREQUENCY TRACKER OUTPUT WITH FL=225 Hz, SRBW=20 Hz.

and this was tracked with only a minimal amount of decision requirements around CPA. The total doppler shift was approximately 0.65 Hz and provided good data for doppler tracking.

E. TARGET TRACKING

Since no bearing information was available corresponding to the frequency data, the IBM 360 Computer was used to generate simulated real time bearings. This was accomplished by programming a pseudo "true track" into the computer so that the target speed and the CPA time were matched as well as possible. The initial starting position was X=500 yards, Y=-1050 yards at time T(1)=190 seconds. The heading and speed used were 90 degrees and 4.5 knots where zero degrees corresponds to the positive X axis. The computer then computed "true bearings" to the target and added random noise values of a programmed standard deviation, SA, to these values. Thus the true track plotted by the computer is only a best estimate of the targets relative position from the buoy.

The X-Y Filter developed by Mitschang [1] was used to process the data and develop the target track. To initialize the filter and commence tracking, the measured bearing must have changed by at least three standard deviations of the measurement noise and the doppler shifted frequency must have decreased from its value at the start of the initialization process. A modification to the filter was attempted so that while initializing, an increasing frequency would be detected as a maneuvering

target. Time, bearing, and frequency values occurring with the maximum frequency detected would then be retained as the initial values to be used when the bearing shift and non-increasing frequency criteria were again satisfied. This would delay the start of the tracking process but would prevent data from a maneuvering target being used to initialize the state equations based on a constant heading, constant speed target. However, indexing problems were encountered and were not resolved in time to include the modification in this report.

The following difference equations developed in Chapter 3 of [1] were used to compute the initial range, heading, and rest frequency of the target.

$$R = -(VP \cdot DELF \cdot DELT)/(f(last) \cdot (DEL\theta)^2 \;) \qquad (4)$$

$$\theta si = \theta ave - 180 - \arcsin((-VP \cdot DELF)/(f(last) \cdot DEL\theta \cdot Vsi)) \qquad (5)$$

$$F0i = Fave \, [1 - (vsi/VP)\cos(\theta si - \theta ave)] \qquad (6)$$

where

VP	=speed of sound propagation
DELF	=doppler shift of the frequency
DELT	=time required to meet initialization criteria
f(last)	=last frequency measured for initialization
DELθ	=change in bearing from sensor to target
θsi	=initial estimate of target heading
θave	=average bearing for the initialization period
Vsi	=initial estimate of target speed

F0i =initial estimate of the rest frequency

Fave =average frequency for the initialization period

Then based on a constant heading, constant speed target, the initial filter state equations are:

X(1) =X position = R cos θave (7)

X(2) =X velocity = Vsi cos θsi (8)

X(3) =Y position = R sin θave (9)

X(4) =Y velocity = Vsi sin θsi (10)

X(5) =Rest frequency = F0i (11)

The initial covariance matrix values are computed by the "direct method" developed in Chapter 4 of [1] and an extended Kalman filtering technique was used to refine the estimates of the target's position, heading, speed, and rest frequency as the problem progresses.

Since the target was maneuvering for the first four minutes of the tape, initialization of the target tracker was commenced at time T(4)=190 seconds, with the values from Table 3 as input data. The average initialization time, AVKJ, varied with the standard deviation of the bearing measurement noise, SA. This time varied from about 4 minutes for SA=5 degrees to about 8 minutes for SA=30 degrees.

IV. RESULTS OBTAINED FROM REAL FREQUENCY INPUTS

Once the frequency tracker has locked on to a stable but doppler shifted frequency, the inputs required of the operator are an estimate of the rest frequency, F0, and an estimate of the target's speed, AVSK. These are "priming" values used in computing the initial heading of the target and affect the ultimate accuracy of the computed track. A third variable affecting the initialization is the standard deviation of the bearing error, SA. As SA increases, the filter takes longer to start tracking and has more data on which to base its original estimates.

The program was run for various combinations of the three variables F0, AVSK, and SA. The true value for F0 was approximately 233.87 Hz and for AVSK was 4.5 knots. An estimated F0 greater than the detected frequency causes a "down-doppler" solution for the initial course. Conversely an estimate of F0 less than the detected frequency results in an "up-doppler" solution for the initial course. Each combination of variables was looped so that one hundred runs were made with that set of inputs and the averaged filtered positions were plotted. The "+" symbol on each plot represents the computed position of the target at time T(1) plus one-half of the initialization period. The range is computed by Equation (4) and the bearing is the average bearing for the initialization period. The true points from which the noisy bearing measurements

were made are plotted with the symbol "*". Averaged filter positions are plotted with an "X". The ascending order of precedence on each plot is +, *, X. Figures 3 through 24 show the performance of the system with real, high resolution frequencies as inputs. F(DET) signifies initial frequency detected.

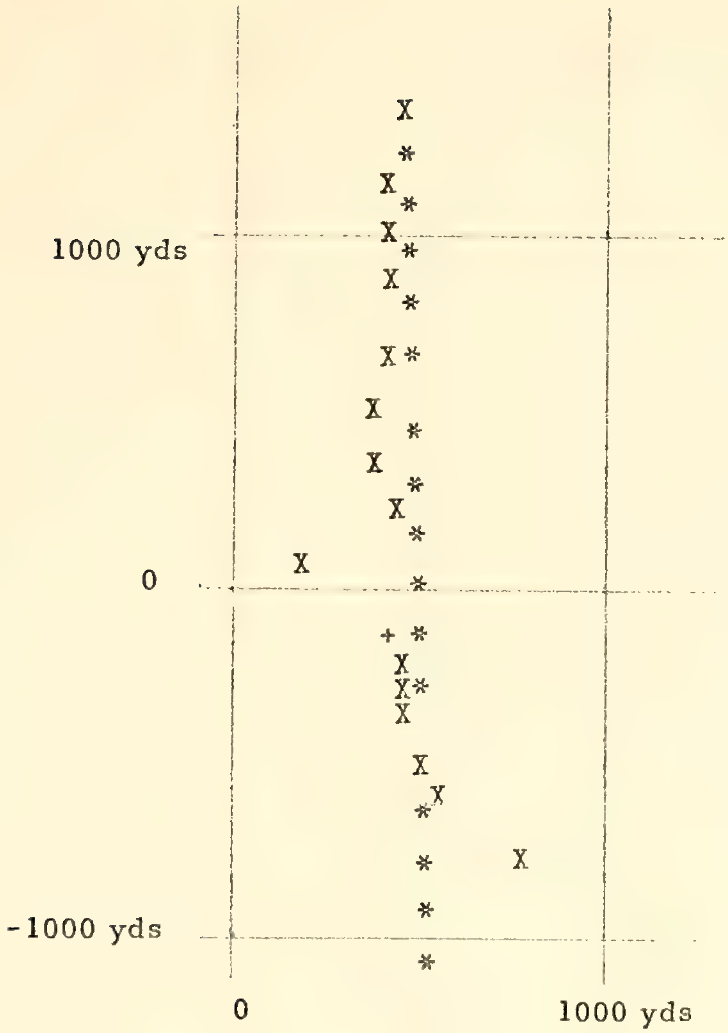


FIGURE 3. FILTER OUTPUT WITH TRUE FO AND AVSK INPUTS, ZERO BEARING ERROR, AND TEN MINUTE INITIALIZATION PERIOD. FIFTH TRUE POINT AND FINAL TRUE POINT SUPPRESSED BY FILTER OUTPUT POSITION

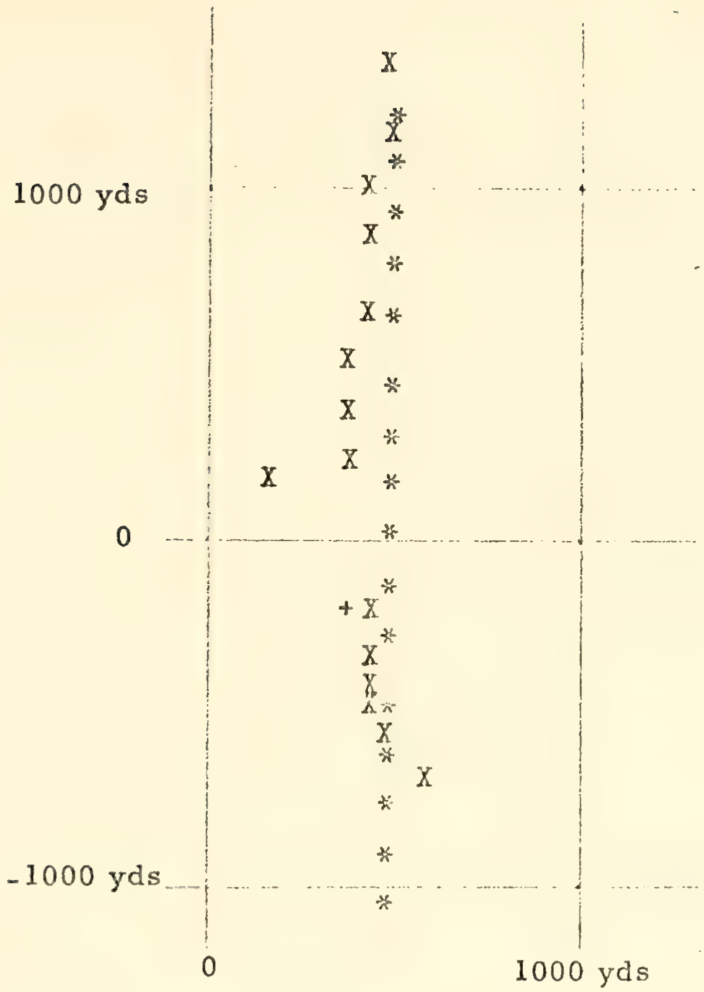


FIGURE 4. FILTER OUTPUT FOR EST. FO ≤ F(DET), EST. AVSK ≈ TRUE AVSK, AND SA = 30°. FINAL TRUE POINT SUPPRESSED BY FILTER OUTPUT FINAL POSITION.

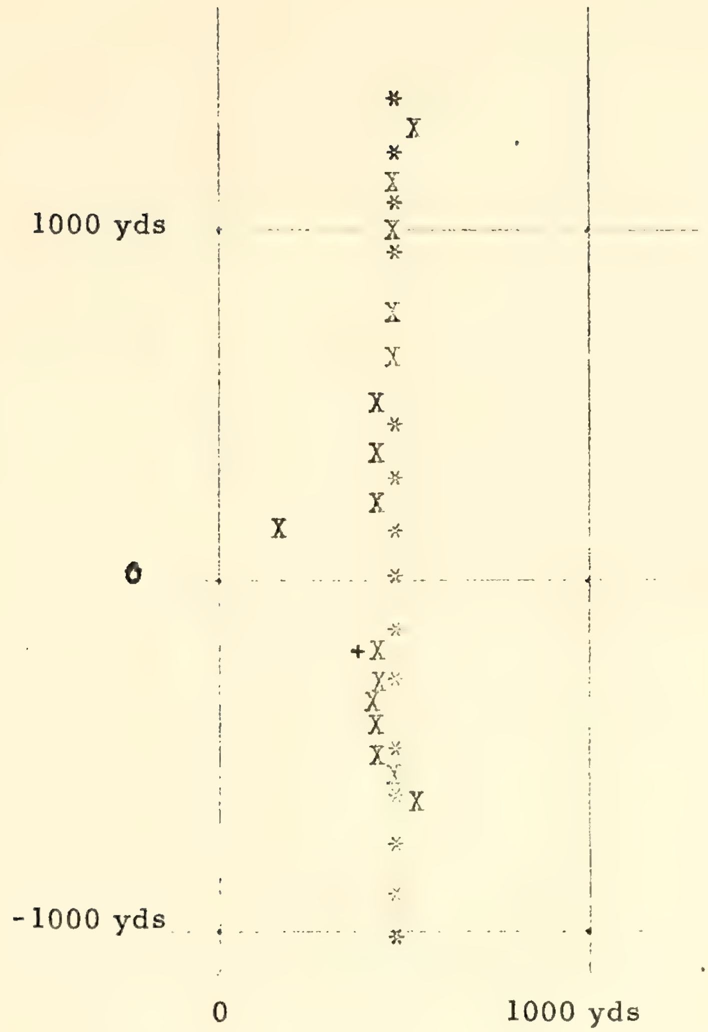


FIGURE 5. FILTER OUTPUT FOR EST. FO HIGHER OR LOWER THAN F(DET), EST. AVSK < TRUE AVSK, and SA = 30°. 12th and 13th TRUE POINTS SUPPRESSED BY FILTER OUTPUTS 13th and 14th POINTS.

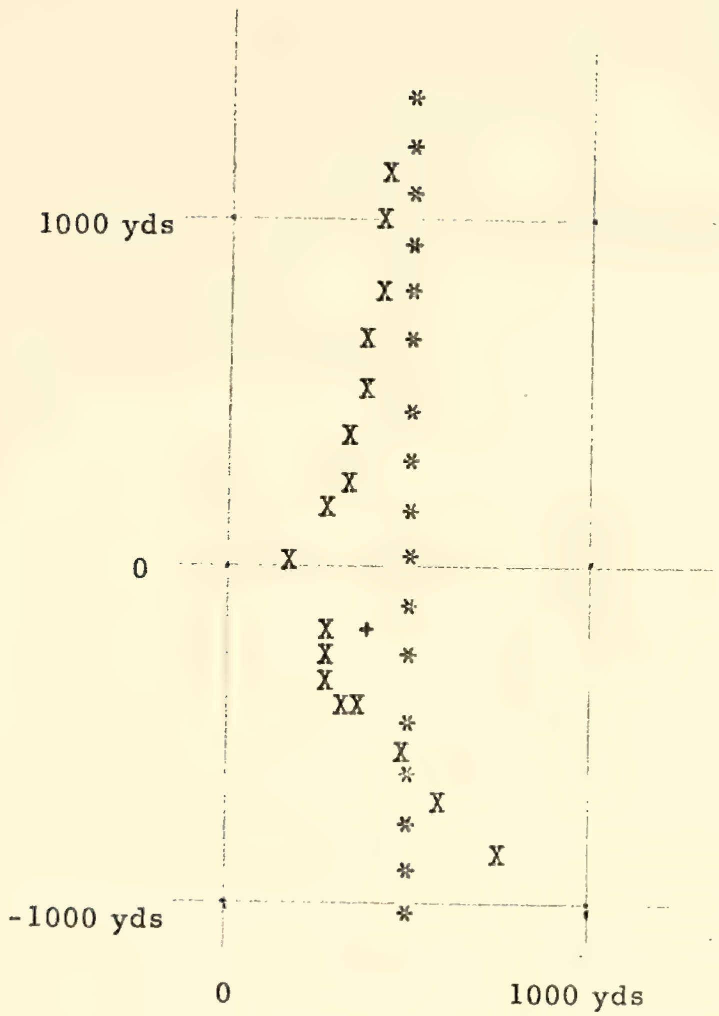


FIGURE 6. FILTER OUTPUT FOR EST. FO $\leq$ F(DET), EST. AVSK > TRUE AVSK, AND SA = 30°.

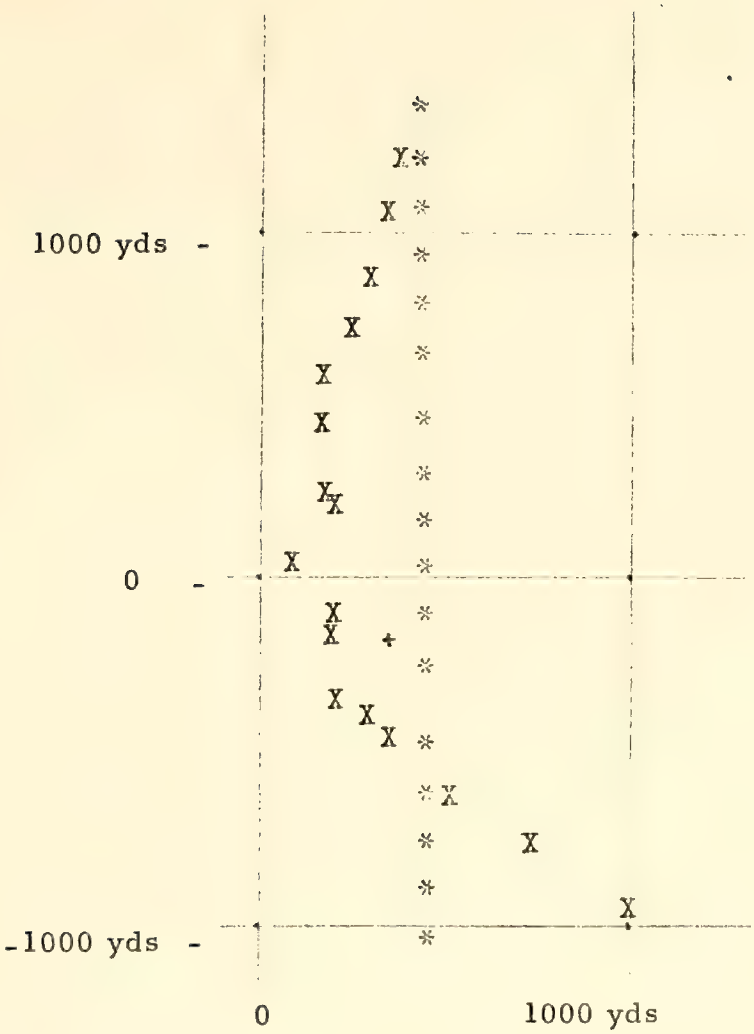


FIGURE 7. FILTER OUTPUT FOR EST. FO > F(DET), EST. AVSK > TRUE AVSK SA = 30°.

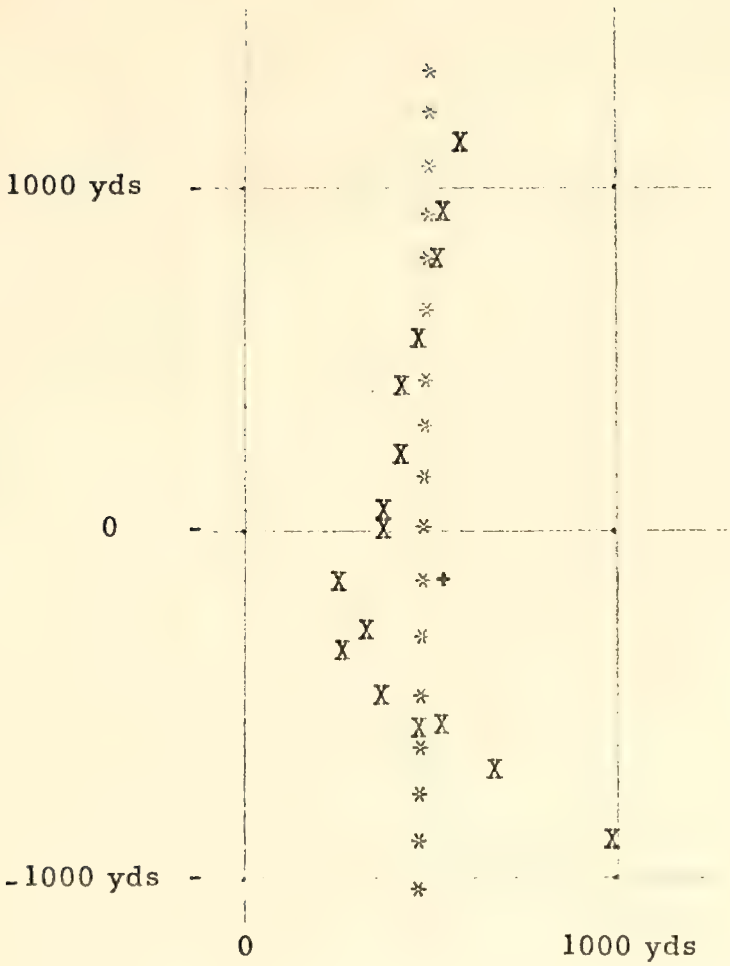


FIGURE 8. FILTER OUTPUT FOR EST. FO $\leq$ F(DET), EST. AVSK > TRUE AVSK BY 90 PERCENT, SA = 30°.

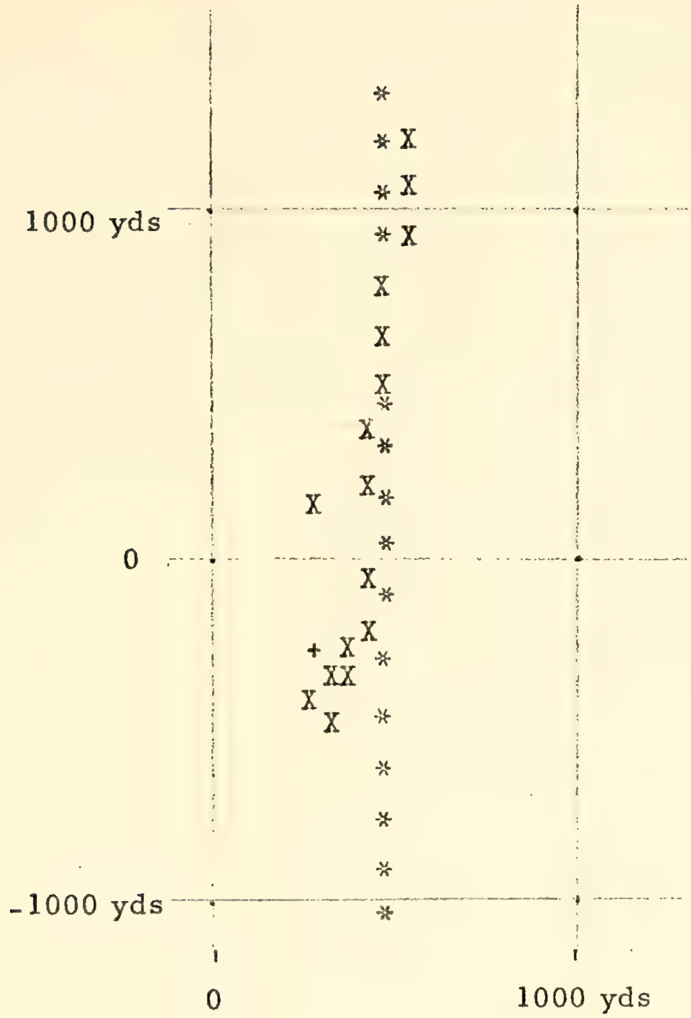


FIGURE 9. FILTER OUTPUT FOR EST. FO HIGHER OR LOWER THAN F(DET), EST. AVSK < TRUE AVSK, AND SA = 15^{o}. 12th and 13th TRUE POINTS SUPPRESSED BY 13th and 14th FILTER OUTPUT POINTS.

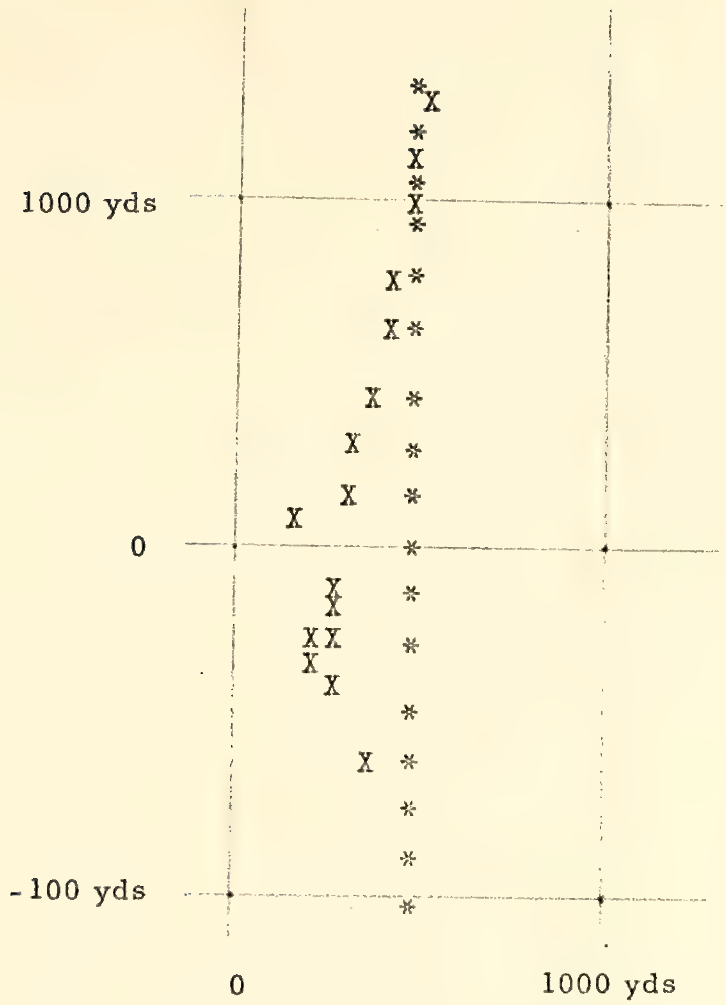


FIGURE 10. FILTER OUTPUT FOR EST. FO HIGHER OR LOWER THAN F(DET), EST. AVSK ≈ TRUE AVSK, AND SA = 15°.

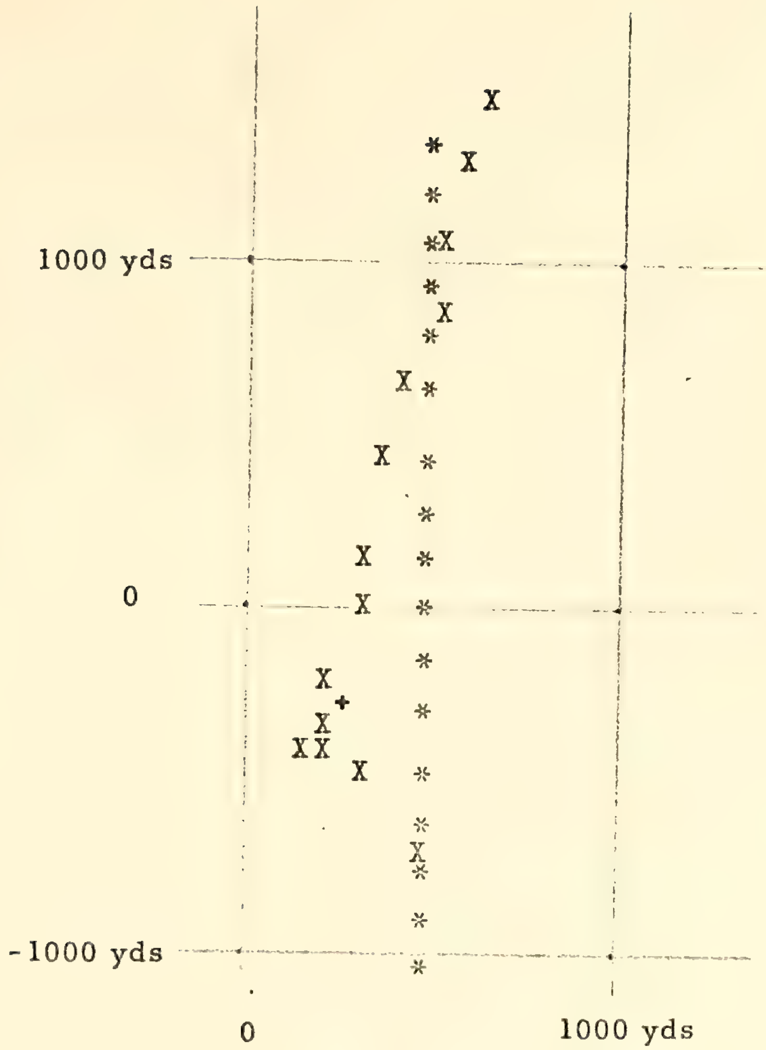


FIGURE 11. FILTER OUTPUT FOR EST. FO HIGHER OR LOWER THAN F (DET), EST. AVSK > TRUE AVSK, AND SA = 15°.

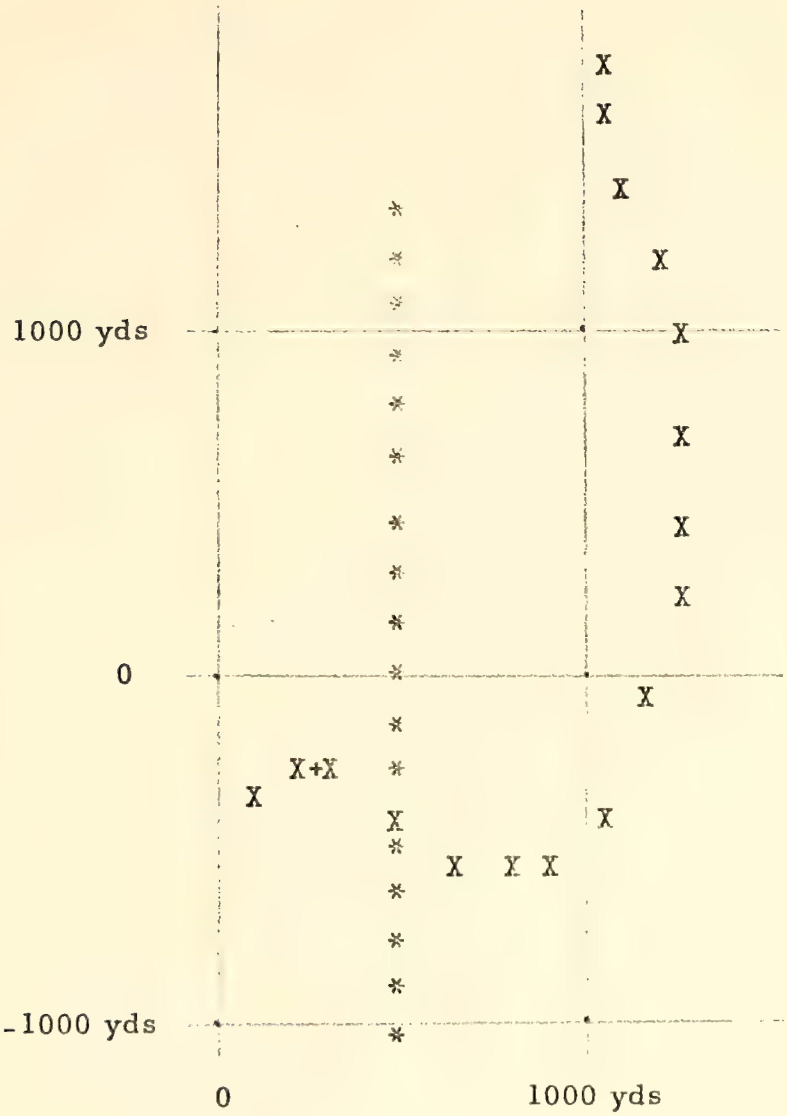


FIGURE 12. FILTER OUTPUT FOR EST. FO > F(DET), EST. AVSK > TRUE AVSK, SA = 15°.

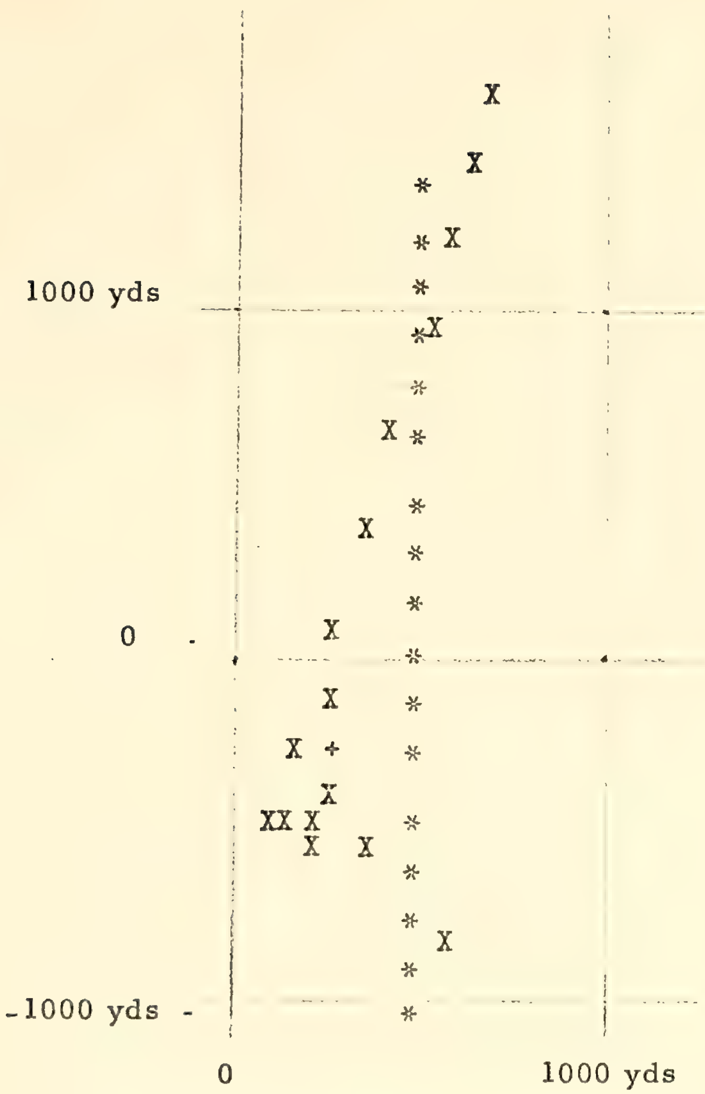


FIGURE 13. FILTER OUTPUT FOR EST. FO $\lessgtr$ F(DET), EST. AVSK > TRUE AVSK, SA = 15°.

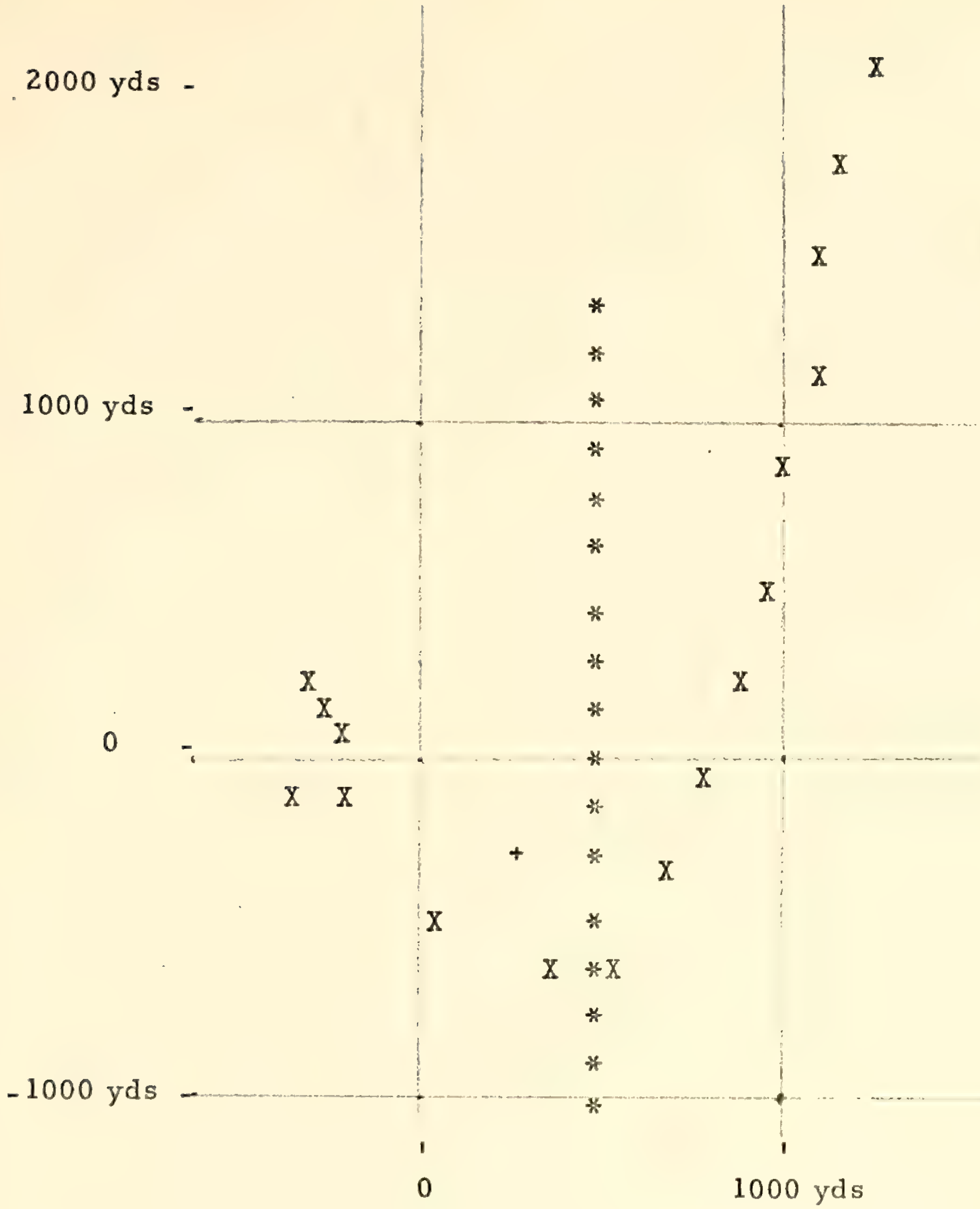


FIGURE 14. FILTER OUTPUT FOR EST. FO > F(DET), EST. AVSK > TRUE AVSK, SA = 15°.

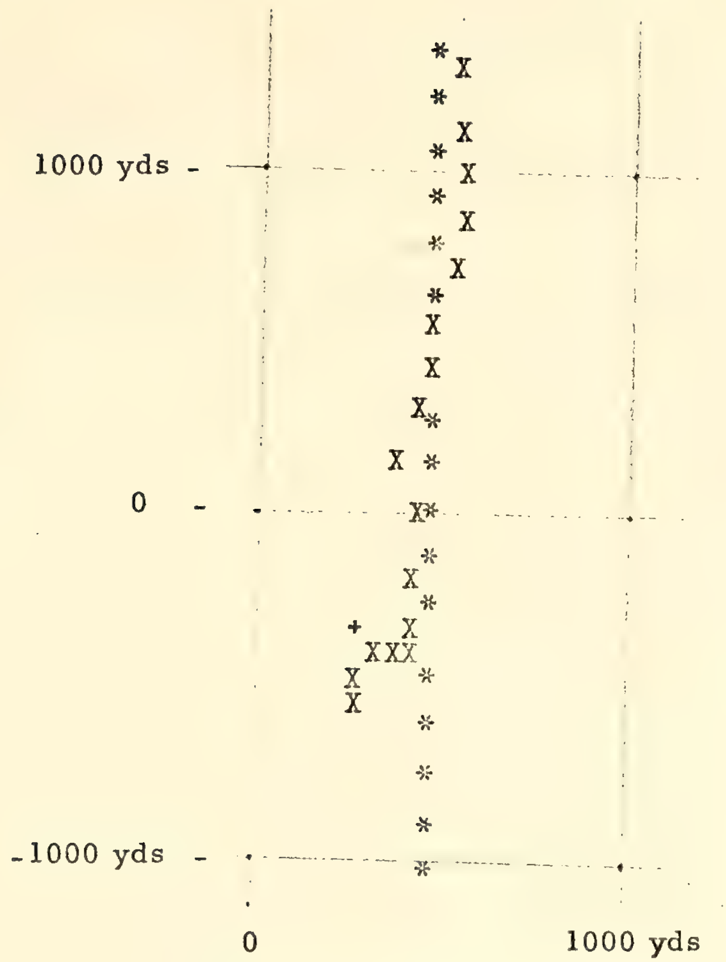


FIGURE 15. FILTER OUTPUT FOR EST. FO HIGHER OR LOWER THAN F(DET), EST. AVSK < TRUE AVSK, AND SA = 10^{o}. 11th TRUE POINT SUPPRESSED BY 11th FILTER OUTPUT POSITION.

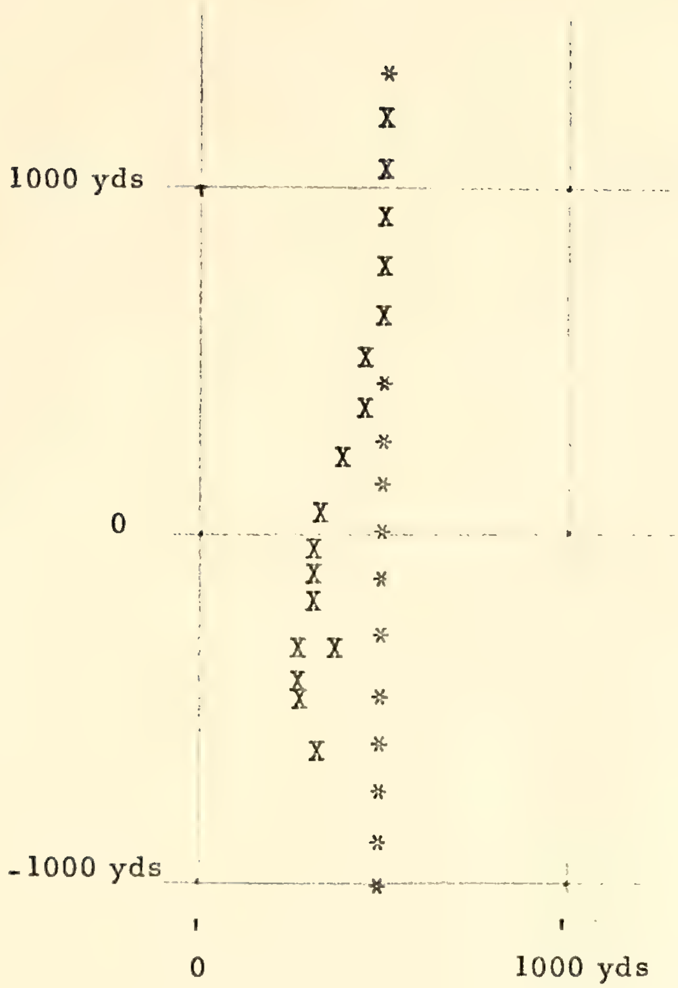


FIGURE 16. FILTER OUTPUT FOR EST. FO HIGHER OR LOWER THAN F(DET), EST. AVSK $\approx$ TRUE AVSK, AND SA = 10°. 12th THROUGH 16th TRUE POINTS SUPPRESSED BY 13th THROUGH 17th FILTER OUTPUT POSITIONS.

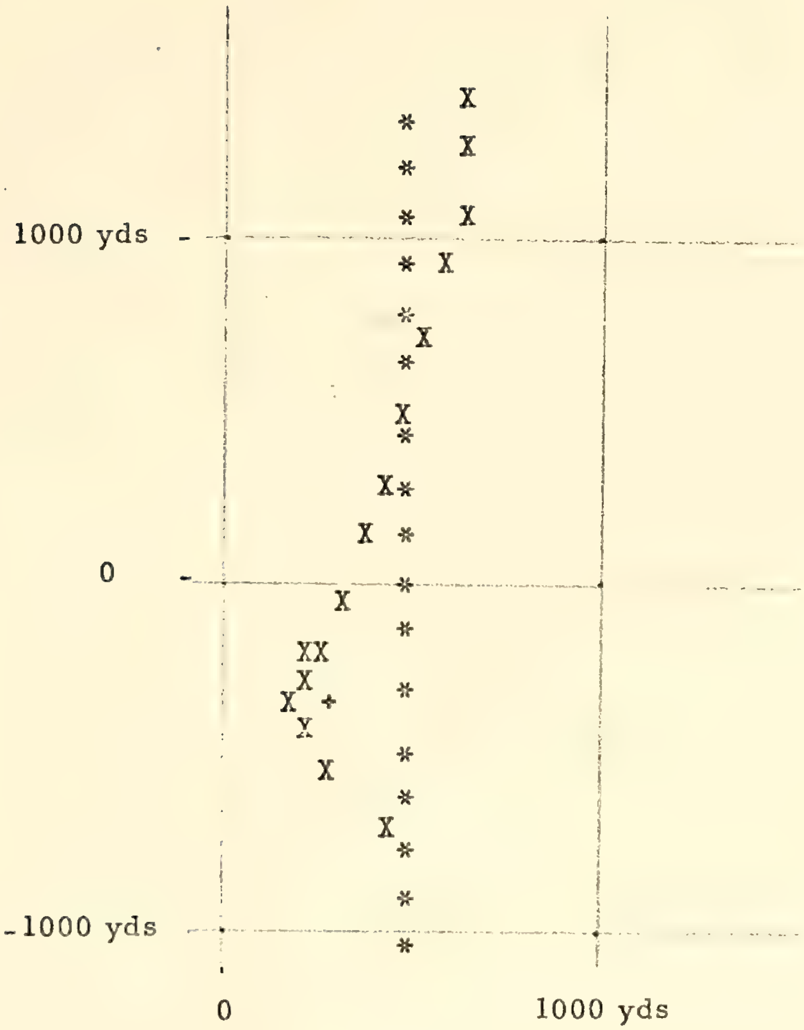


FIGURE 17. FILTER OUTPUT FOR EST. FO < F(DET), EST. AVSK > TRUE AVSK, SA = 10°.

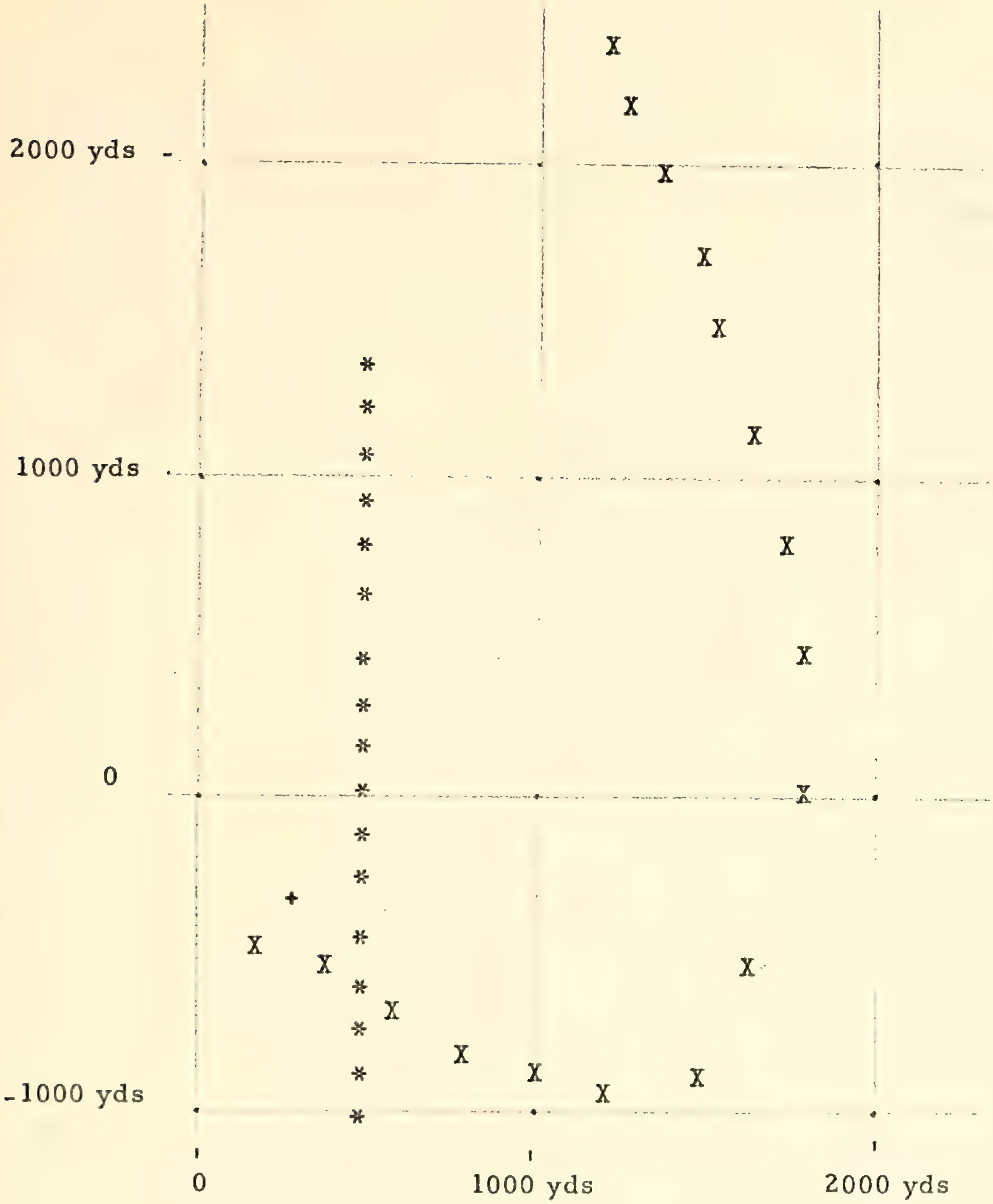


FIGURE 18. FILTER OUTPUT FOR EST. FO > F(DET),
EST. AVSK > TRUE AVSK, SA = 10^{o}.

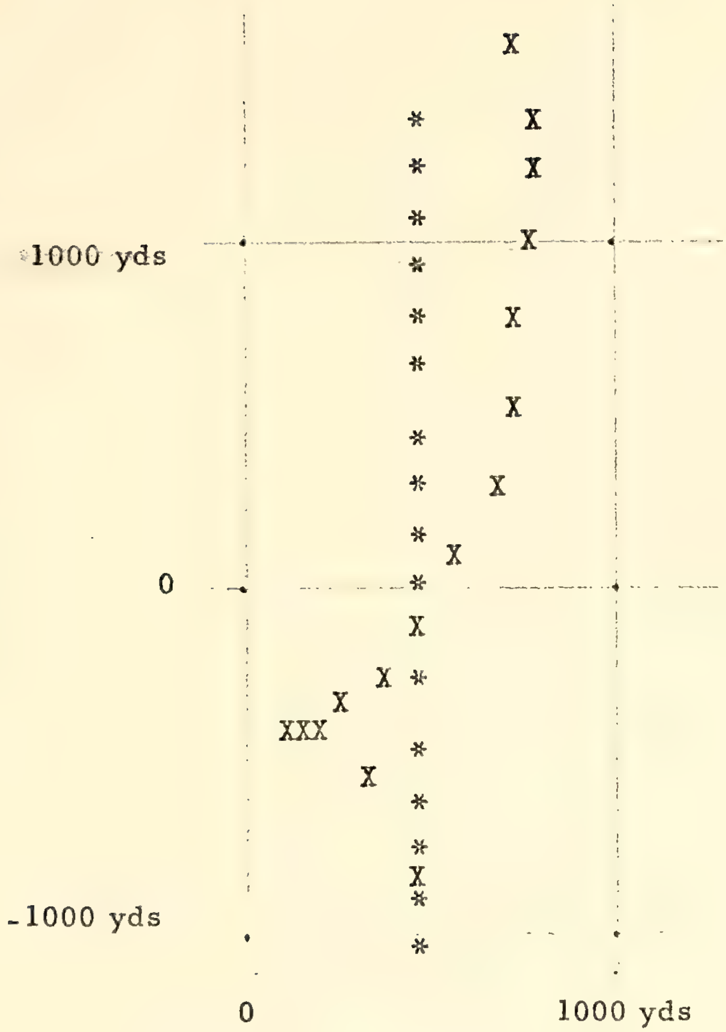


FIGURE 19. FILTER OUTPUT FOR EST. FO $\leq$ F(DET), EST. AVSK $>$ TRUE AVSK, SA = 10°. 7th TRUE POINT SUPPRESSED BY 8th FILTER OUTPUT POINT.

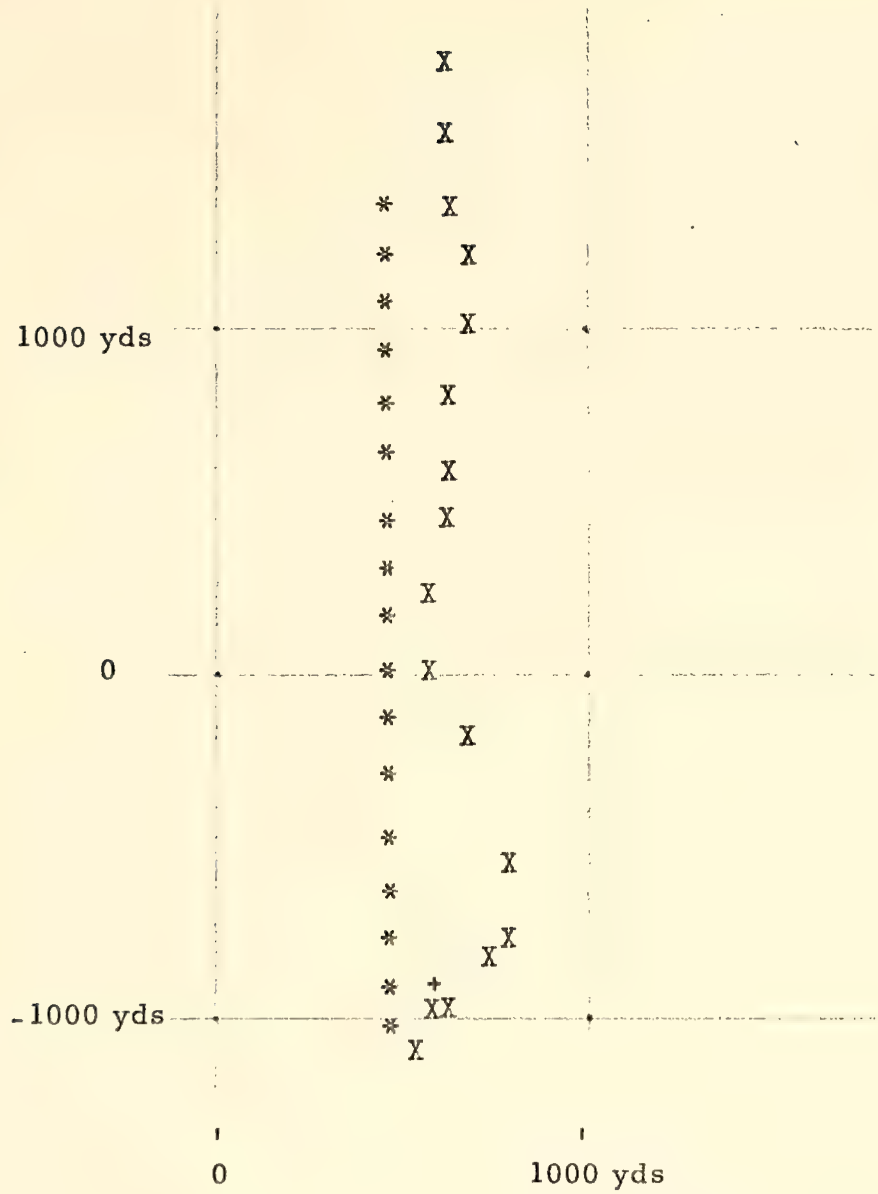


FIGURE 20. FILTER OUTPUT FOR EST. FO HIGHER OR LOWER THAN F(DET), EST. AVSK < TRUE AVSK, AND SA = 5°.

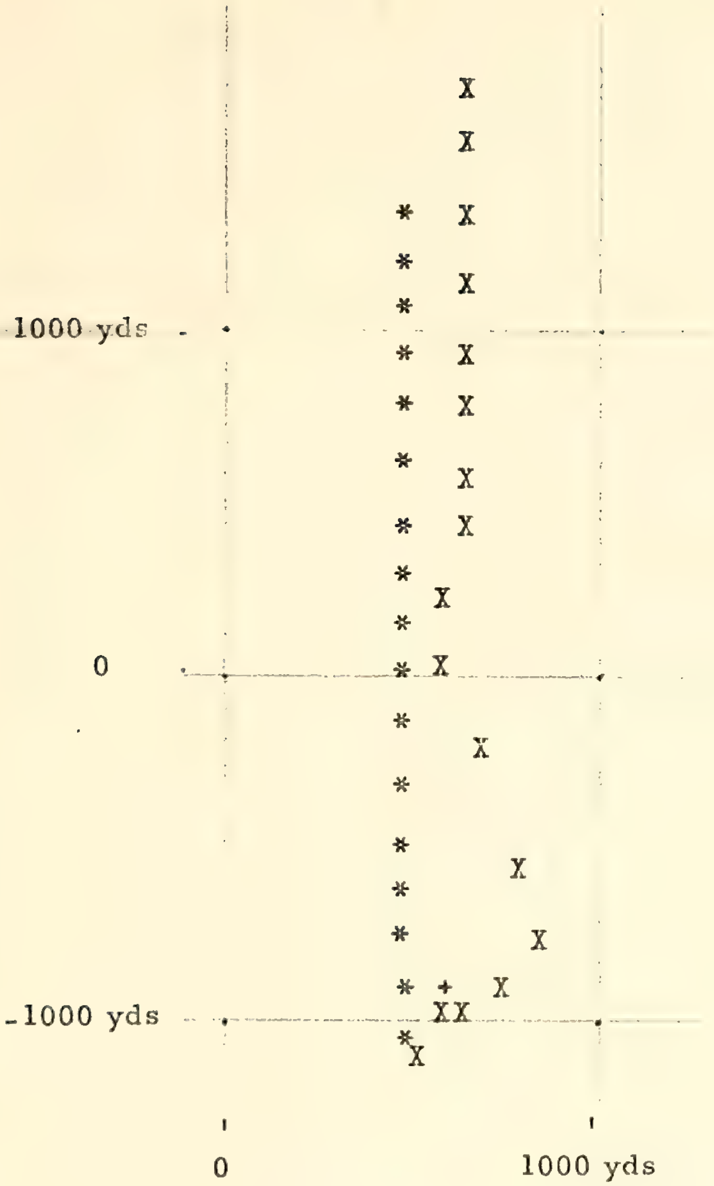


FIGURE 21. FILTER OUTPUT FOR EST. FO HIGHER OR LOWER THAN F(DET), EST. AVSK ≈ TRUE AVSK, AND SA = 5°.

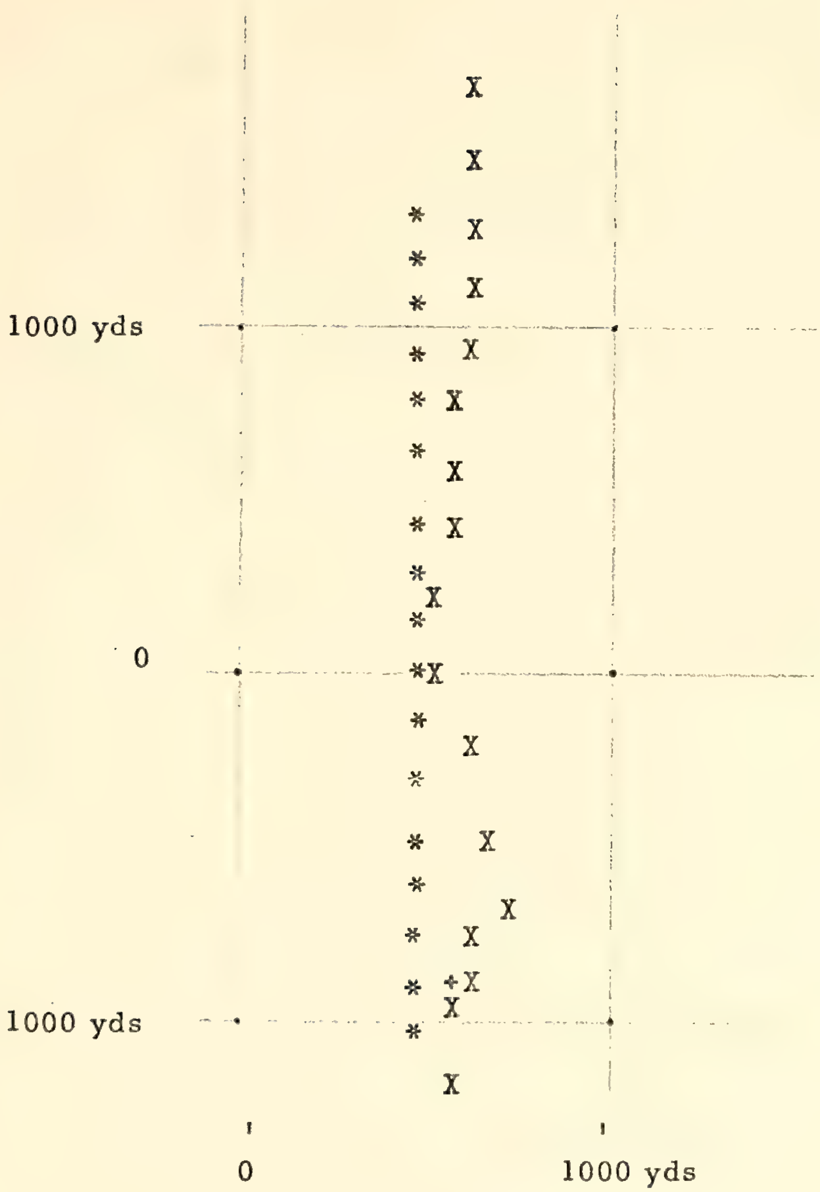


FIGURE 22. FILTER OUTPUT FOR EST. FO < F(DET), EST. AVSK > TRUE AVSK, SA = 5°.

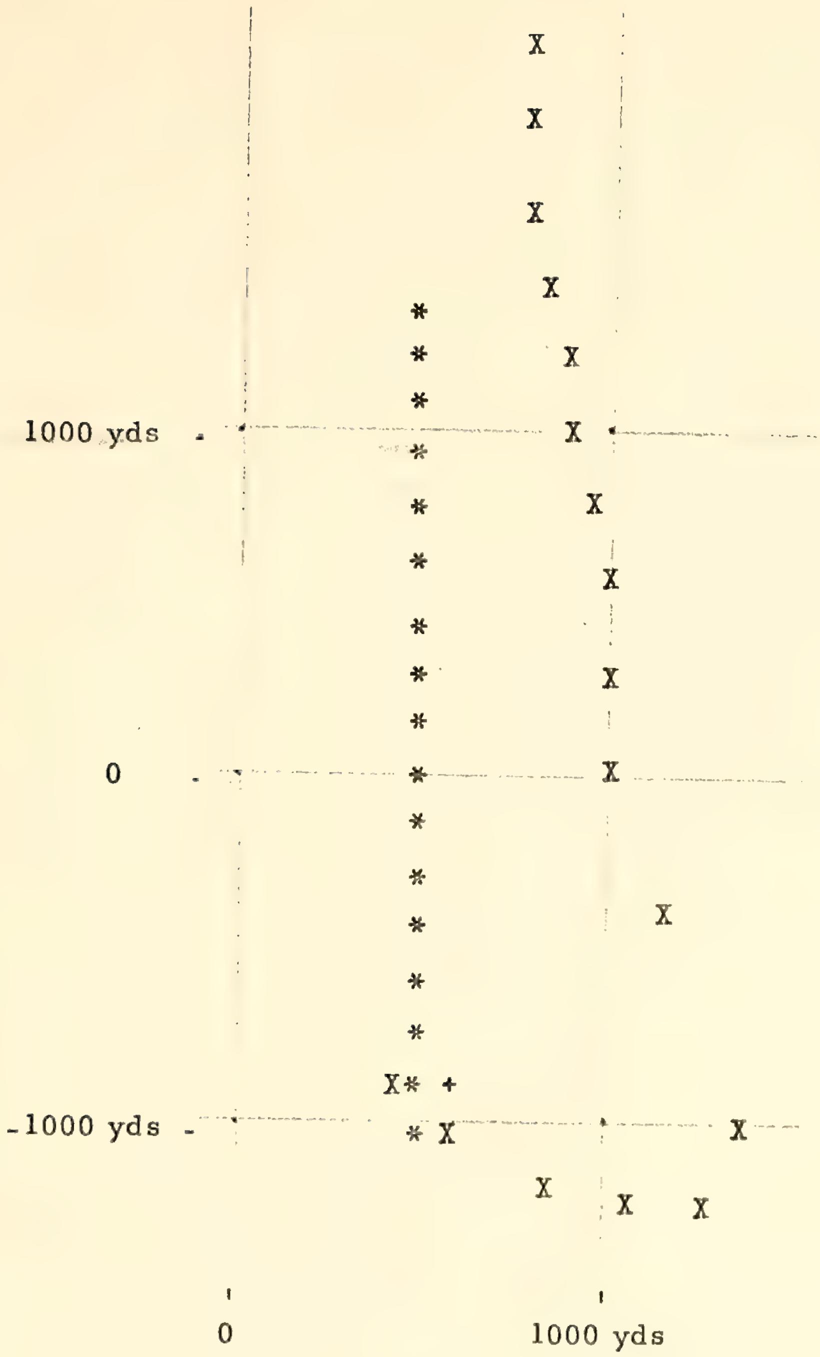


FIGURE 23. FILTER OUTPUT FOR EST. FO > F(DET), EST. AVSK > TRUE AVSK, SA = 5°.

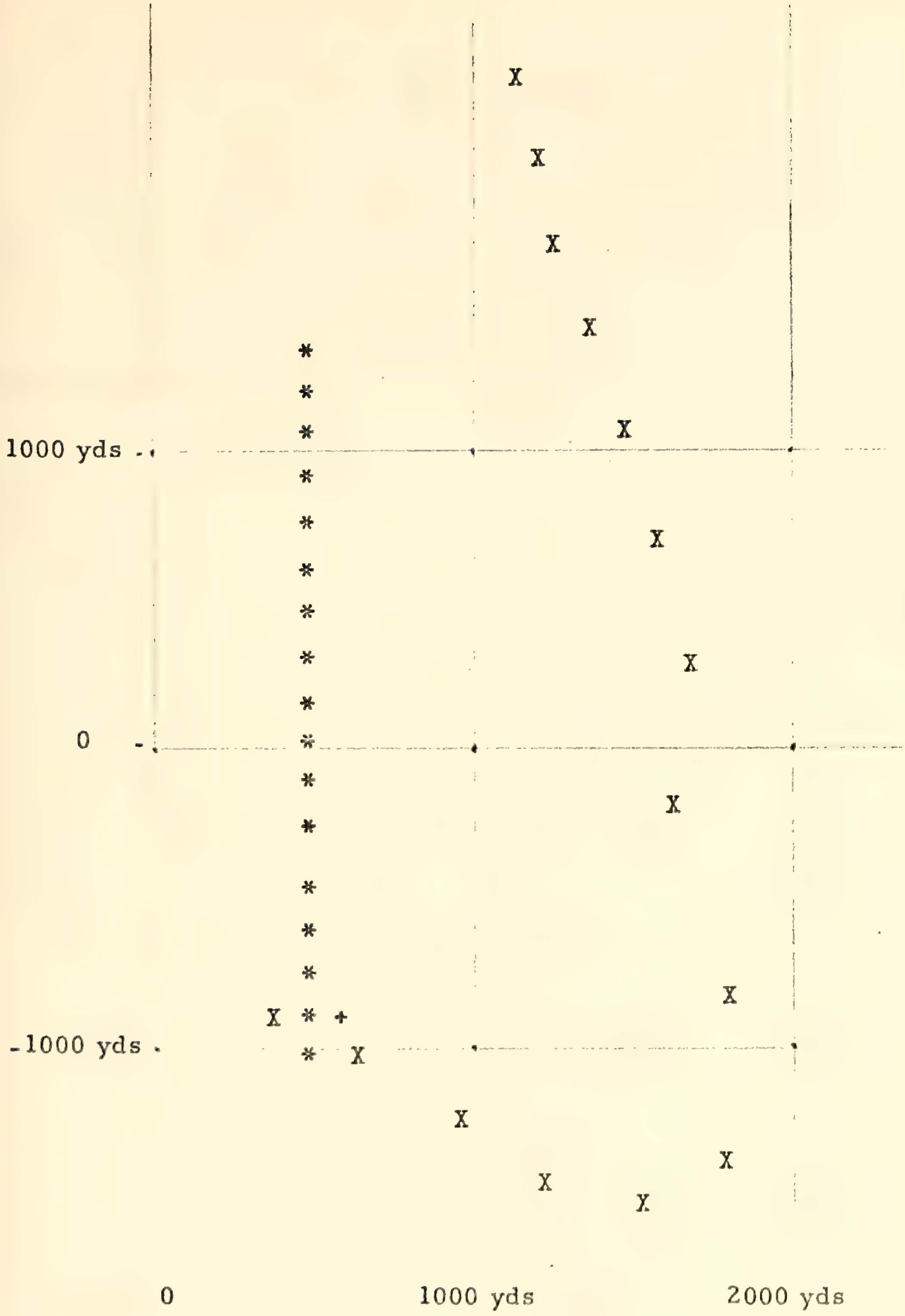


FIGURE 24. FILTER OUTPUT FOR EST. FO > F(DET), EST. AVSK =2·TRUE AVSK, SA = 5°.

V. CONCLUSIONS

The automatic frequency tracker developed in this report has been shown to be adequate for tracking a doppler-shifting frequency in a favorable signal-to-noise ratio environment. The width of the tracking window would have to be increased for a higher speed target unless the transforms were computed at closer time intervals. A loss of signal would result in the last center bin frequency being retained as the signal being tracked unless a spurious signal with more power than the chosen minimum appeared in the window. Therefore, under marginal signal-to-noise ratio conditions, an operator would be required to monitor the frequency tracker output to insure that after a "lost track" condition occurred, any "regain track" operation was indeed occurring on the previous signal being tracked.

The procedure of using Equation (3) to extend the frequency resolution of the output above that of the FFT processing is dependent upon having a reasonable approximation of the ambient noise level. Computing a new estimate in each transform results in higher power levels than the true ambient noise level being used when the target is near CPA. Since the ratio of two numbers, A/B, is not equal to the ratio (A-K)/(B-K) where K is a constant, the subtraction of the corrupted estimate of ambient noise level causes an error in the value of the resolved frequency. However, in comparing the amplitudes of the signal and

noise estimates around CPA (from Tables I, II, and III), the signal is 150 to 200 times as large as the corrupted ambient noise estimate. The resultant error on the resolved frequency is on the order of magnitude of 10^{-4}Hz and was considered negligible. As the range at CPA increases, the signal power level decreases and its corrupting influence on the ambient noise level approximation is decreased. Thus as long as the increased average power level in the window is caused by the target being tracked, no appreciable error occurs and the resolution of the overall system has been extended beyond the resolution of the FFT processing.

With real frequency inputs and reasonable initial estimates of the rest frequency and target speed, the Mitschang Filter provided target tracks in excellent agreement with the known emitter locations and probable emitter locations. Thus a true single sensor fix appears possible using existing hardware and techniques. Further testing is needed where exact target locations are known and real measured bearings are available corresponding to the real frequency measurements.

COMPUTER OUTPUT

```
SOUND SPEED COMPUTATION



 TEMPERATURE= 48.0 DEG F     SALINITY= 35.0 PPT     DEPTH=   60.0 FEET
SOUND PROPAGATION SPEED =     1625.53 YARDS PER SECOND

 INPUTS FOR FREQUENCY TRACKER SET.
LOWER FREQUENCY LIMIT OF THE SEARCH WINDOW =   220.0
SEARCH WINDOW BANDWIDTH =  20

TRANSFORMS TAKEN ONE MINUTE APART.  TIME IS IN SECONDS.
```

```
FILE   10.0 STATISTICS:             MAX VALUE      MIN VALUE      MEAN VALUE      STD DEV
BASED ON SAMPLE SIZE OF 20480   0.243063E 00  -0.301820E 00  -0.190762E-02   0.327662E-01

FILE   10.0 - FOURIER TRANSFORM

FILE   10.0 IN FFT.    10240 TERMS
        FACTORS:
            4    4    2    2    5    2    4    4    0    0    0    0    0

FILE   10.0 - POWER SPECTRUM

THRESHOLD VALUE COMPUTED =0.00000006  FOR THIS TRANSFORM.

TBIN( 1)=  70 COMPUTED BY MAIN PROGRAM.

FILE  10.0  LARGEST COEFFICIENT IN 220.0HZ  TO 240.0HZ FREQUENCY BAND IS IN BIN K BELOW:

3 BIN RESOLUTION TRACKING VALUES: CENTER BIN FREQUENCY=  223.45  TIME( 1)=   10.0
                   FTRK( 1)= 223.437

 POWER COEFFICIENTS IN BINS (K-1)/K/(K+1) ARE:    0.00000069  0.00000206  0.0

RUN COMPLETED FOR THIS FILE NUMBER.
```

```
FILE   40.0 STATISTICS:            MAX VALUE      MIN VALUE      MEAN VALUE      STD DEV
BASED ON SAMPLE SIZE OF 20480   0.255112E 00  -0.245352E 00  -0.190913E-02   0.285688E-01

FILE   40.0 - FOURIER TRANSFORM

FILE   40.0 IN FFT.    10240 TERMS
        FACTORS:
           4    4    2    2    5    2    4    4.   0    0    0    0    0

FILE   40.0 - POWER SPECTRUM

THRESHOLD VALUE COMPUTED =0.00000005  FOR THIS TRANSFORM.

TBIN( 2)=  71 COMPUTED BY MAIN PROGRAM.

FILE  40.0  LARGEST COEFFICIENT IN 220.0HZ  TO 240.0HZ FREQUENCY BAND IS IN BIN K BELOW:

3 BIN RESOLUTION TRACKING VALUES: CENTER BIN FREQUENCY=  223.50  TIME( 2)=   70.0
                     FTRK( 2)= 223.481

 POWER COEFFICIENTS IN BINS (K-1)/K/(K+1) ARE:    0.00000094  0.00000112  0.00000011


            ----TRACKING WINDOW CHECK----

MANUEVERING TARGET OR NOISE: DOPPLER SHIFT UP    1 BINS.

RUN COMPLETED FOR THIS FILE NUMBER.
```

```
FILE   70.0 STATISTICS:           MAX VALUE      MIN VALUE      MEAN VALUE      STD DEV
BASED ON SAMPLE SIZE OF 20480   0.349400E 00  -0.345968E 00  -0.193838E-02   0.382910E-01

FILE   70.0 - FOURIER TRANSFORM

FILE   70.0 IN FFT.     10240 TERMS
          FACTORS:
              4    4    2    2    5    2    4    4    0    0    0    0    0

FILE   70.0 - POWER SPECTRUM

THRESHOLD VALUE COMPUTED =0.00000005  FOR THIS TRANSFORM.

TBIN( 3)=  71 COMPUTED BY MAIN PROGRAM.

FILE  70.0  LARGEST COEFFICIENT IN 220.0HZ  TO 240.0HZ FREQUENCY BAND IS IN BIN K BELOW:

3 BIN RESOLUTION TRACKING VALUES: CENTER BIN FREQUENCY=  223.50  TIME( 3)=  130.0
                    FTRK( 3)= 223.495

 POWER COEFFICIENTS IN BINS (K-1)/K/(K+1) ARE:    0.00000015  0.00000061  0.00000007


            ----TRACKING WINDOW CHECK----

RUN COMPLETED FOR THIS FILE NUMBER.
```

```
FILE  100.0 STATISTICS:            MAX VALUE      MIN VALUE      MEAN VALUE       STD DEV
BASED ON SAMPLE SIZE OF 20480   0.281263E 00  -0.261961E 00  -0.192759E-02   0.349617E-01

FILE  100.0 - FOURIER TRANSFORM

FILE  100.0 IN FFT.    10240 TERMS
          FACTORS:
             4    4    2    2    5    2    4    4    0    0    0    0    0

FILE  100.0 - POWER SPECTRUM

THRESHOLD VALUE COMPUTED =0.00000005  FOR THIS TRANSFORM.

TBIN( 4)= 285 COMPUTED BY MAIN PROGRAM.

FILE 100.0  LARGEST COEFFICIENT IN 220.0HZ  TO 240.0HZ FREQUENCY BAND IS IN BIN K BELOW:

3 BIN RESOLUTION TRACKING VALUES: CENTER BIN FREQUENCY=  234.20  TIME( 4)=  190.0
                     FTRK( 4)= 234.224

 POWER COEFFICIENTS IN BINS (K-1)/K/(K+1) ARE:    0.0          0.00000077  0.00000072


            ----TRACKING WINDOW CHECK----

BIN SHIFT OF  214 BINS. RECHECK TRACKED FREQ.

NEW CENTER BIN : RESET TBIN( 4) TO   72

3 BIN RESOLUTION TRACKING VALUES: CENTER BIN FREQUENCY=  223.55  TIME( 4)=  190.0
                 NEW FTRK( 4)= 223.556

 POWER COEFFICIENTS IN BINS (K-1)/K/(K+1) ARE:    0.00000002  0.00000052  0.00000009

RUN COMPLETED FOR THIS FILE NUMBER.
```

```
FILE  130.0 STATISTICS:            MAX VALUE      MIN VALUE      MEAN VALUE      STD DEV
BASED ON SAMPLE SIZE OF 20480   0.194444E 00  -0.174759E 00  -0.194470E-02   0.285963E-01

FILE  130.0 - FOURIER TRANSFORM

FILE  130.0 IN FFT.     10240 TERMS
         FACTORS:
            4    4    2    2    5    2    4    4    0    0    0    0    0

FILE  130.0 - POWER SPECTRUM

THRESHOLD VALUE COMPUTED =0.00000006  FOR THIS TRANSFORM.

TBIN( 5)=  71 COMPUTED BY MAIN PROGRAM.

FILE 130.0  LARGEST COEFFICIENT IN 220.0HZ  TO 240.0HZ FREQUENCY BAND IS IN BIN K BELOW:

3 BIN RESOLUTION TRACKING VALUES: CENTER BIN FREQUENCY=  223.50  TIME( 5)=  250.0
                 FTRK( 5)= 223.489

 POWER COEFFICIENTS IN BINS (K-1)/K/(K+1) ARE:    0.00000086  0.00000254  0.00000009


          ----TRACKING WINDOW CHECK----

RUN COMPLETED FOR THIS FILE NUMBER.
```

```
FILE  160.0 STATISTICS:           MAX VALUE      MIN VALUE      MEAN VALUE       STD DEV
BASED ON SAMPLE SIZE OF 20480   0.206948E 00  -0.206238E 00  -0.193671E-02   0.304564E-01

FILE  160.0 - FOURIER TRANSFORM

FILE  160.0 IN FFT.     10240 TERMS
        FACTORS:
           4    4    2    2    5    2    4    4    0    0    0    0    0

FILE  160.0 - POWER SPECTRUM

THRESHOLD VALUE COMPUTED =0.00000006  FOR THIS TRANSFORM.

TBIN( 6)=  70 COMPUTED BY MAIN PROGRAM.

FILE 160.0  LARGEST COEFFICIENT IN 220.0HZ  TO 240.0HZ FREQUENCY BAND IS IN BIN K BELOW:

3 BIN RESOLUTION TRACKING VALUES: CENTER BIN FREQUENCY=  223.45  TIME( 6)=  310.0
                      FTRK( 6)= 223.473

 POWER COEFFICIENTS IN BINS (K-1)/K/(K+1) ARE:    0.00000006  0.00000218  0.00000201


             ----TRACKING WINDOW CHECK----

RUN COMPLETED FOR THIS FILE NUMBER.
```

```
FILE  190.0 STATISTICS:              MAX VALUE     MIN VALUE      MEAN VALUE      STD DEV
BASED ON SAMPLE SIZE OF 20480   0.233394E 00  -0.232250E 00  -0.195899E-02   0.295174E-01

FILE  190.0 - FOURIER TRANSFORM

FILE  190.0 IN FFT.    10240 TERMS
        FACTORS:
            4    4    2    2    5    2    4    4    0    0    0    0    0

FILE  190.0 - POWER SPECTRUM

THRESHOLD VALUE COMPUTED =0.00000009  FOR THIS TRANSFORM.

TBIN( 7)= 283 COMPUTED BY MAIN PROGRAM.

FILE 190.0  LARGEST COEFFICIENT IN 220.0HZ  TO 240.0HZ FREQUENCY BAND IS IN BIN K BELOW:

3 BIN RESOLUTION TRACKING VALUES: CENTER BIN FREQUENCY=  234.10  TIME( 7)=  370.0
                 FTRK( 7)= 234.102

 POWER COEFFICIENTS IN BINS (K-1)/K/(K+1) ARE:    0.00000084  0.00000826  0.00000117


          ----TRACKING WINDOW CHECK----

BIN SHIFT OF  213 BINS. RECHECK TRACKED FREQ.

NEW CENTER BIN : RESET TBIN( 7) TO   69

3 BIN RESOLUTION TRACKING VALUES: CENTER BIN FREQUENCY=  223.40  TIME( 7)=  370.0
              NEW FTRK( 7)= 223.420

 POWER COEFFICIENTS IN BINS (K-1)/K/(K+1) ARE:    0.00000008  0.00000490  0.00000344

RUN COMPLETED FOR THIS FILE NUMBER.
```

```
FILE  220.0 STATISTICS:          MAX VALUE      MIN VALUE      MEAN VALUE      STD DEV
BASED ON SAMPLE SIZE OF 20480   0.251516E 00  -0.260181E 00  -0.193467E-02   0.314328E-01

FILE  220.0 - FOURIER TRANSFORM

FILE  220.0 IN FFT.    10240 TERMS
         FACTORS:
            4    4    2    2    5    2    4    4    0    0    0    0    0

FILE  220.0 - POWER SPECTRUM

THRESHOLD VALUE COMPUTED =0.00000008  FOR THIS TRANSFORM.

TBIN( 8)= 284 COMPUTED BY MAIN PROGRAM.

FILE 220.0  LARGEST COEFFICIENT IN 220.0HZ  TO 240.0HZ FREQUENCY BAND IS IN BIN K BELOW:

3 BIN RESOLUTION TRACKING VALUES: CENTER BIN FREQUENCY=  234.15  TIME( 8)=  430.0
                     FTRK( 8)= 234.144

 POWER COEFFICIENTS IN BINS (K-1)/K/(K+1) ARE:    0.00000291  0.00000707  0.00000158


           ----TRACKING WINDOW CHECK----

BIN SHIFT OF  215 BINS. RECHECK TRACKED FREQ.

NEW CENTER BIN : RESET TBIN( 8) TO   72

**CHECKING POWER IN OLD CENTER BIN, TBIN(JJ-1).  IF SIGNIFICANT, IPRINT VALUE FOLLOWS.

IPRINT= 3  LAST CENTER BIN STILL SIGNIFICANT.  FURTHER CHECKS NEEDED.

LAST CENTER BIN USED WITH NEW POWER COEFFICIENTS. MODIFIED VALUES FOLLOW.

3 BIN RESOLUTION TRACKING VALUES: CENTER BIN FREQUENCY=  223.40  TIME( 8)=  430.0
                 NEW FTRK( 8)= 223.407

 POWER COEFFICIENTS IN BINS (K-1)/K/(K+1) ARE:    0.0         0.00000064  0.00000011

RUN COMPLETED FOR THIS FILE NUMBER.
```

```
FILE  250.0 STATISTICS:            MAX VALUE      MIN VALUE      MEAN VALUE      STD DEV
BASED ON SAMPLE SIZE OF 20480   0.208288E 00  -0.182077E 00  -0.194680E-02   0.320234E-01

FILE  250.0 - FOURIER TRANSFORM

FILE  250.0 IN FFT.    10240 TERMS
        FACTORS:
           4    4    2    2    5    2    4    4    0    0    0    0    0

FILE  250.0 - POWER SPECTRUM

THRESHOLD VALUE COMPUTED =0.00000024  FOR THIS TRANSFORM.

TBIN( 9)= 284 COMPUTED BY MAIN PROGRAM.

FILE 250.0  LARGEST COEFFICIENT IN 220.0HZ  TO 240.0HZ FREQUENCY BAND IS IN BIN K BELOW:

3 BIN RESOLUTION TRACKING VALUES: CENTER BIN FREQUENCY=  234.15  TIME( 9)=  490.0
                     FTRK( 9)= 234.132

 POWER COEFFICIENTS IN BINS (K-1)/K/(K+1) ARE:    0.00002056  0.00003291  0.00000131


            ----TRACKING WINDOW CHECK----

BIN SHIFT OF  215 BINS. RECHECK TRACKED FREQ.

NEW CENTER BIN : RESET TBIN( 9) TO   70

3 BIN RESOLUTION TRACKING VALUES: CENTER BIN FREQUENCY=  223.45  TIME( 9)=  490.0
                 NEW FTRK( 9)= 223.434

 POWER COEFFICIENTS IN BINS (K-1)/K/(K+1) ARE:    0.00000435  0.00000743  0.00000049

RUN COMPLETED FOR THIS FILE NUMBER.
```

```
FILE  280.0 STATISTICS:            MAX VALUE      MIN VALUE      MEAN VALUE      STD DEV
BASED ON SAMPLE SIZE OF 20480   0.220928E 00  -0.223862E 00  -0.198426E-02   0.307096E-01

FILE  280.0 - FOURIER TRANSFORM

FILE  280.0 IN FFT.    10240 TERMS
        FACTORS:
           4    4    2    2    5    2    4    4    0    0    0    0    0

FILE  280.0 - POWER SPECTRUM

THRESHOLD VALUE COMPUTED =0.00000041  FOR THIS TRANSFORM.

TBIN(10)= 284 COMPUTED BY MAIN PROGRAM.

FILE 280.0  LARGEST COEFFICIENT IN 220.0HZ  TO 240.0HZ FREQUENCY BAND IS IN BIN K BELOW:

3 BIN RESOLUTION TRACKING VALUES: CENTER BIN FREQUENCY=  234.15  TIME(10)=  550.0
                     FTRK(10)= 234.130

 POWER COEFFICIENTS IN BINS (K-1)/K/(K+1) ARE:    0.00003518  0.00004815  0.00000075


            ----TRACKING WINDOW CHECK----

BIN SHIFT OF  214 BINS. RECHECK TRACKED FREQ.

NEW CENTER BIN : RESET TBIN(10) TO   71

3 BIN RESOLUTION TRACKING VALUES: CENTER BIN FREQUENCY=  223.50  TIME(10)=  550.0
                 NEW FTRK(10)= 223.488

 POWER COEFFICIENTS IN BINS (K-1)/K/(K+1) ARE:    0.00000837  0.00002131  0.00000122

RUN COMPLETED FOR THIS FILE NUMBER.
```

```
FILE  310.0 STATISTICS:            MAX VALUE      MIN VALUE      MEAN VALUE       STD DEV
BASED ON SAMPLE SIZE OF 20480   0.267322E 00  -0.241567E 00  -0.209375E-02   0.424228E-01

FILE  310.0 - FOURIER TRANSFORM

FILE  310.0 IN FFT.    10240 TERMS
          FACTORS:
              4    4    2    2    5    2    4    4    0    0    0    0    0

FILE  310.0 - POWER SPECTRUM

THRESHOLD VALUE COMPUTED =0.00000068  FOR THIS TRANSFORM.

TBIN(11)=  69 COMPUTED BY MAIN PROGRAM.

FILE 310.0  LARGEST COEFFICIENT IN 220.0HZ  TO 240.0HZ FREQUENCY BAND IS IN BIN K BELOW:

3 BIN RESOLUTION TRACKING VALUES: CENTER BIN FREQUENCY=  223.40  TIME(11)=  610.0
                 FTRK(11)= 223.396

 POWER COEFFICIENTS IN BINS (K-1)/K/(K+1) ARE:    0.00002000  0.00010429  0.00000939


         ----TRACKING WINDOW CHECK----

**CHECKING POWER IN OLD CENTER BIN, TBIN(JJ-1).  IF SIGNIFICANT, IPRINT VALUE FOLLOWS.

RUN COMPLETED FOR THIS FILE NUMBER.
```

```
FILE  340.0 STATISTICS:            MAX VALUE      MIN VALUE      MEAN VALUE      STD DEV
BASED ON SAMPLE SIZE OF 20480   0.221991E 00  -0.229415E 00  -0.207766E-02   0.363091E-01

FILE  340.0 - FOURIER TRANSFORM

FILE  340.0 IN FFT.    10240 TERMS
         FACTORS:
               4    4    2    2    5    2    4    4    0    0    0    0    0

FILE  340.0 - POWER SPECTRUM

THRESHOLD VALUE COMPUTED =0.00000050  FOR THIS TRANSFORM.

TBIN(12)= 276 COMPUTED BY MAIN PROGRAM.

FILE 340.0  LARGEST COEFFICIENT IN 220.0HZ  TO 240.0HZ FREQUENCY BAND IS IN BIN K BELOW:

3 BIN RESOLUTION TRACKING VALUES: CENTER BIN FREQUENCY=  233.75  TIME(12)=  670.0
                       FTRK(12)= 233.756

 POWER COEFFICIENTS IN BINS (K-1)/K/(K+1) ARE:    0.00000367  0.00006029  0.00001350


            ----TRACKING WINDOW CHECK----

BIN SHIFT OF  207 BINS. RECHECK TRACKED FREQ.

NEW CENTER BIN : RESET TBIN(12) TO   62

**CHECKING POWER IN OLD CENTER BIN, TBIN(JJ-1).  IF SIGNIFICANT, IPRINT VALUE FOLLOWS.

3 BIN RESOLUTION TRACKING VALUES: CENTER BIN FREQUENCY=  223.05  TIME(12)=  670.0
                   NEW FTRK(12)= 223.063

 POWER COEFFICIENTS IN BINS (K-1)/K/(K+1) ARE:    0.00000212  0.00004795  0.00002132

RUN COMPLETED FOR THIS FILE NUMBER.
```

```
FILE  370.0 STATISTICS:              MAX VALUE      MIN VALUE      MEAN VALUE      STD DEV
BASED ON SAMPLE SIZE OF 20480   0.217568E 00  -0.254127E 00  -0.198310E-02   0.369957E-01

FILE  370.0 - FOURIER TRANSFORM

FILE  370.0 IN FFT.    10240 TERMS
       FACTORS:
          4    4    2    2    5    2    4    4    0    0    0    0    0

FILE  370.0 - POWER SPECTRUM

THRESHOLD VALUE COMPUTED =0.00000026  FOR THIS TRANSFORM.

TBIN(13)=  60 COMPUTED BY MAIN PROGRAM.

FILE 370.0  LARGEST COEFFICIENT IN 220.0HZ  TO 240.0HZ FREQUENCY BAND IS IN BIN K BELOW:

3 BIN RESOLUTION TRACKING VALUES: CENTER BIN FREQUENCY=  222.95  TIME(13)=  730.0
                 FTRK(13)= 222.960

 POWER COEFFICIENTS IN BINS (K-1)/K/(K+1) ARE:    0.00000546  0.00002554  0.00001492


          ----TRACKING WINDOW CHECK----

**CHECKING POWER IN OLD CENTER BIN, TBIN(JJ-1).  IF SIGNIFICANT, IPRINT VALUE FOLLOWS.

RUN COMPLETED FOR THIS FILE NUMBER.
```

```
FILE  400.0 STATISTICS:          MAX VALUE      MIN VALUE      MEAN VALUE      STD DEV
BASED ON SAMPLE SIZE OF 20480   0.243037E 00  -0.292045E 00  -0.201376E-02   0.403838E-01

FILE  400.0 - FOURIER TRANSFORM

FILE  400.0 IN FFT.    10240 TERMS
        FACTORS:
            4    4    2    2    5    2    4    4    0    0    0    0    0

FILE  400.0 - POWER SPECTRUM

THRESHOLD VALUE COMPUTED =0.00000016  FOR THIS TRANSFORM.

TBIN(14)=  61 COMPUTED BY MAIN PROGRAM.

FILE 400.0  LARGEST COEFFICIENT IN 220.0HZ  TO 240.0HZ FREQUENCY BAND IS IN BIN K BELOW:

3 BIN RESOLUTION TRACKING VALUES: CENTER BIN FREQUENCY=  223.00  TIME(14)=  790.0
                    FTRK(14)= 222.995

 POWER COEFFICIENTS IN BINS (K-1)/K/(K+1) ARE:    0.00000587  0.00002119  0.00000288


            ----TRACKING WINDOW CHECK----

MANUEVERING TARGET OR NOISE: DOPPLER SHIFT UP    1 BINS.

RUN COMPLETED FOR THIS FILE NUMBER.
```

```
FILE  430.0 STATISTICS:              MAX VALUE      MIN VALUE      MEAN VALUE      STD DEV
BASED ON SAMPLE SIZE OF 20480    0.186438E 00  -0.202603E 00  -0.197654E-02   0.297088E-01

FILE  430.0 - FOURIER TRANSFORM

FILE  430.0 IN FFT.     10240 TERMS
         FACTORS:
             4    4    2    2    5    2    4    4    0    0    0    0    0

FILE  430.0 - POWER SPECTRUM

THRESHOLD VALUE COMPUTED =0.00000014  FOR THIS TRANSFORM.

TBIN(15)= 272 COMPUTED BY MAIN PROGRAM.

FILE 430.0  LARGEST COEFFICIENT IN 220.0HZ  TO 240.0HZ FREQUENCY BAND IS IN BIN K BELOW:

3 BIN RESOLUTION TRACKING VALUES: CENTER BIN FREQUENCY=  233.55   TIME(15)=  850.0
                      FTRK(15)= 233.563

 POWER COEFFICIENTS IN BINS (K-1)/K/(K+1) ARE:    0.00000307  0.00001079  0.00000878


            ----TRACKING WINDOW CHECK----

BIN SHIFT OF  211 BINS. RECHECK TRACKED FREQ.

NEW CENTER BIN : RESET TBIN(15) TO   60

3 BIN RESOLUTION TRACKING VALUES: CENTER BIN FREQUENCY=  222.95   TIME(15)=  850.0
                  NEW FTRK(15)= 222.938

 POWER COEFFICIENTS IN BINS (K-1)/K/(K+1) ARE:    0.00000252  0.00000322  0.00000088

RUN COMPLETED FOR THIS FILE NUMBER.
```

```
FILE  460.0 STATISTICS:            MAX VALUE      MIN VALUE       MEAN VALUE       STD DEV
BASED ON SAMPLE SIZE OF 20480   0.233344E 00  -0.235275E 00  -0.198056E-02   0.314997E-01

FILE  460.0 - FOURIER TRANSFORM

FILE  460.0 IN FFT.    10240 TERMS
          FACTORS:
              4    4    2    2    5    2    4    4    0    0    0    0    0

FILE  460.0 - POWER SPECTRUM

THRESHOLD VALUE COMPUTED =0.00000010  FOR THIS TRANSFORM.

TBIN(16)= 272 COMPUTED BY MAIN PROGRAM.

FILE 460.0  LARGEST COEFFICIENT IN 220.0HZ  TO 240.0HZ FREQUENCY BAND IS IN BIN K BELOW:

3 BIN RESOLUTION TRACKING VALUES: CENTER BIN FREQUENCY=  233.55  TIME(16)=  910.0
                      FTRK(16)= 233.558

 POWER COEFFICIENTS IN BINS (K-1)/K/(K+1) ARE:    0.00000075  0.00001018  0.00000303


            ----TRACKING WINDOW CHECK----

BIN SHIFT OF  212 BINS. RECHECK TRACKED FREQ.

NEW CENTER BIN : RESET TBIN(16) TO   59

3 BIN RESOLUTION TRACKING VALUES: CENTER BIN FREQUENCY=  222.90  TIME(16)=  910.0
                  NEW FTRK(16)= 222.882

 POWER COEFFICIENTS IN BINS (K-1)/K/(K+1) ARE:    0.00000221  0.00000245  0.00000037

RUN COMPLETED FOR THIS FILE NUMBER.
```

```
FILE  490.0 STATISTICS:          MAX VALUE      MIN VALUE      MEAN VALUE      STD DEV
BASED ON SAMPLE SIZE OF 20480   0.404760E 00  -0.459331E 00  -0.201675E-02   0.375543E-01

FILE  490.0 - FOURIER TRANSFORM

FILE  490.0 IN FFT.    10240 TERMS
        FACTORS:
            4    4    2    2    5    2    4    4    0    0    0    0    0

FILE  490.0 - POWER SPECTRUM

THRESHOLD VALUE COMPUTED =0.00000004  FOR THIS TRANSFORM.

TBIN(17)=  59 COMPUTED BY MAIN PROGRAM.

FILE 490.0  LARGEST COEFFICIENT IN 220.0HZ  TO 240.0HZ FREQUENCY BAND IS IN BIN K BELOW:

3 BIN RESOLUTION TRACKING VALUES: CENTER BIN FREQUENCY=  222.90  TIME(17)=  970.0
                   FTRK(17)= 222.898

 POWER COEFFICIENTS IN BINS (K-1)/K/(K+1) ARE:    0.00000002  0.00000060  0.0


           ----TRACKING WINDOW CHECK----

RUN COMPLETED FOR THIS FILE NUMBER.
```

```
FILE  520.0 STATISTICS:            MAX VALUE      MIN VALUE      MEAN VALUE      STD DEV
BASED ON SAMPLE SIZE OF 20480   0.364448E 00  -0.261167E 00  -0.197170E-02   0.368306E-01

FILE  520.0 - FOURIER TRANSFORM

FILE  520.0 IN FFT.    10240 TERMS
        FACTORS:
            4    4    2    2    5    2    4    4    0    0    0    0    0

FILE  520.0 - POWER SPECTRUM

THRESHOLD VALUE COMPUTED =0.00000006  FOR THIS TRANSFORM.

TBIN(18)= 272 COMPUTED BY MAIN PROGRAM.

FILE 520.0  LARGEST COEFFICIENT IN 220.0HZ  TO 240.0HZ FREQUENCY BAND IS IN BIN K BELOW:

3 BIN RESOLUTION TRACKING VALUES: CENTER BIN FREQUENCY=  233.55  TIME(18)= 1030.0
                   FTRK(18)= 233.545

 POWER COEFFICIENTS IN BINS (K-1)/K/(K+1) ARE:    0.00000073  0.00000356  0.00000026


          ----TRACKING WINDOW CHECK----

BIN SHIFT OF  213 BINS. RECHECK TRACKED FREQ.

NEW CENTER BIN : RESET TBIN(18) TO   59

3 BIN RESOLUTION TRACKING VALUES: CENTER BIN FREQUENCY=  222.90  TIME(18)= 1030.0
               NEW FTRK(18)= 222.886

 POWER COEFFICIENTS IN BINS (K-1)/K/(K+1) ARE:    0.00000059  0.00000112  0.00000009

RUN COMPLETED FOR THIS FILE NUMBER.
```

```
FILE  550.0 STATISTICS:           MAX VALUE     MIN VALUE      MEAN VALUE      STD DEV
BASED CN SAMPLE SIZE OF 20480   0.210356E 00  -0.225759E 00  -0.195410E-02   0.330490E-01

FILE  550.0 - FOURIER TRANSFORM

FILE  550.0 IN FFT.    10240 TERMS
        FACTORS:
            4    4    2    2    5    2    4    4    0    0    0    0    0

FILE  550.0 - POWER SPECTRUM

THRESHOLD VALUE COMPUTED =0.00000005  FOR THIS TRANSFORM.

TBIN(19)= 272 COMPUTED BY MAIN PROGRAM.

FILE 550.0  LARGEST COEFFICIENT IN 220.0HZ  TO 240.0HZ FREQUENCY BAND IS IN BIN K BELOW:

3 BIN RESOLUTION TRACKING VALUES: CENTER BIN FREQUENCY=  233.55  TIME(19)= 1090.0
                    FTRK(19)= 233.530

 POWER COEFFICIENTS IN BINS (K-1)/K/(K+1) ARE:    0.00000083  0.00000130  0.0


            ----TRACKING WINDOW CHECK----

BIN SHIFT OF  213 BINS. RECHECK TRACKED FREQ.

SIGNAL FOUND IN TRACKING WINDOW IS BELOW MINIMUM VALUE.  CONTACT LOST.

RUN COMPLETED FOR THIS FILE NUMBER.
```

```
FILE  580.0 STATISTICS:          MAX VALUE       MIN VALUE       MEAN VALUE       STD DEV
BASED ON SAMPLE SIZE OF 20480   0.239689E 00  -0.254579E 00  -0.197033E-02   0.343977E-01

FILE  580.0 - FOURIER TRANSFORM

FILE  580.0 IN FFT.    10240 TERMS
       FACTORS:
          4    4    2    2    5    2    4    4    0    0    0    0    0

FILE  580.0 - POWER SPECTRUM

THRESHOLD VALUE COMPUTED =0.00000005  FOR THIS TRANSFORM.

TBIN(20)=  59 COMPUTED BY MAIN PROGRAM.

FILE 580.0  LARGEST COEFFICIENT IN 220.0HZ  TO 240.0HZ FREQUENCY BAND IS IN BIN K BELOW:

3 BIN RESOLUTION TRACKING VALUES: CENTER BIN FREQUENCY=  222.90  TIME(20)= 1150.0
                 FTRK(20)= 222.901

 POWER COEFFICIENTS IN BINS (K-1)/K/(K+1) ARE:    0.00000019  0.00000115  0.00000024


          ----TRACKING WINDOW CHECK----

RUN COMPLETED FOR THIS FILE NUMBER.

END OF PROGRAM.
```

```
// EXEC FORTCLGP,REGION.GO=225K
//FORT.SYSIN  DD *
      INTEGER SAMPR,SRBW,TBIN(60),BNSHF,MAXSF
      REAL YMAG(60)
      REAL Y(20480),YA(400),YL(400),TIME(60),FTRK(60)
      DIMENSION IY(20480)
      PI=3.14159
C
C
      WRITE (6,1)
    1 FORMAT ('1',////////////,47X,'COMPUTER OUTPUT',////
     1,17X,'SOUND SPEED COMPUTATION',///)
C
C         COMPUTATION OF SOUND PROPAGATION SPEED.
C         TEMP = TEMPERATURE IN DEG FARENHEIT
C         SAL = SALINITY IN PARTS PER THOUSAND
C         DEPTH = SELECTED DEPTH IN FEET
C         VP = SPEED OF PROPAGATION IN YARDS PER SECOND
C         SET DESIRED VALUES FOR PROBLEM VARIABLES.
      TEMP=48.
      SAL=35.0
      DEPTH=60.0
      VP=1476.1+3.97*TEMP-0.018*(TEMP)**2+1.42*(SAL-35.0)+0.0057*DEPTH
      WRITE (6,10) TEMP,SAL,DEPTH,VP
   10 FORMAT ('0',17X,'TEMPERATURE=',F5.1,' DEG F',4X,'SALINITY=',
     1F5.1,' PPT',4X,'DEPTH=',F7.1,' FEET',/,17X,
     2'SOUND PROPAGATION SPEED = ',F10.2,' YARDS PER SECOND')
C
C         SAMPR=SAMPLE RATE IN SAMPLES PER SECOND
      SAMPR=512
C         NREC=NUMBER OF RECORDS PER TRANSFORM
      NREC=10
C         NOTE-- THERE ARE TWO SECONDS OF DATA PER RECORD.
C         L=NUMBER OF BINS REQUIRED PER TRANSFORM.
      L=2*SAMPR*NREC*2
C         RESOL=FREQUENCY RESOLUTION OF THE FFT PROCESSING.
      RESOL=1./FLOAT(2*NREC)
C         SRBW=SEARCH WINDOW BANDWIDTH.
      SRBW=20
      N=SRBW*20
      FL=220.
      WRITE (6,11) FL,SRBW
   11 FORMAT ('0',17X,'INPUTS FOR FREQUENCY TRACKER SET.',/,17X,
     1'LOWER FREQUENCY LIMIT OF THE SEARCH WINDOW = ',F7.1,
     2/,17X,'SEARCH WINDOW BANDWIDTH = ',I3,//,17X,'TRANSFORMS TAKEN ',
     3'ONE MINUTE APART.  TIME IS IN SECONDS.')
C         NOTE--FILE CARRIES THE INDEX NUMBER OF THE LAST
C           RECORD READ.
```

```
      FILE=0.0
C        NSTRT=FIRST RECORD NUMBER TO BE ANALYZED.
      NSTRT=1
C        NTFM=NUMBER OF TRANSFORMS TO BE COMPUTED.
      NTFM=20
C
C
      DO 420  JJ=1,NTFM
C
C        INITIALIZE MATRICIES TO ZERO.
C
      DO 20 I=1,L
      Y(I)=0.0
      IY(I)=0
   20 CONTINUE
C
C
      DO 30 I=1,N
      YA(I)=0.0
      YL(I)=0.0
   30 CONTINUE
C
      N1=NSTRT-1
      IF (N1.LT.1) GO TO 50
C
C        DUMMY READ TO SKIP OVER RECORDS THAT ARE NOT
C          TO BE ANALYZED.
C
      DO 40 J=1,N1
      FILE=INT(FILE)+1.
   40 READ (2,END=50) (IY(I),I=1,2048,2)
C
   50 CONTINUE
C
C        DATA TO BE ANALYZED LOADED HERE IN STEPS OF TWO.
C        SINCE DATA POINT VALUES ARE REAL, ZERO VALUES
C        ARE LEFT IN THE IMAJINARY (EVEN) BINS.
      JB=1
C
      DO 60 J=1,NREC
      JE=JB+2047
      READ (2,END=60) (IY(MM),MM=JB,JE,2)
      FILE=INT(FILE)+1.
      JB=JE+1
   60 CONTINUE
C
C
C        IY MATRIX CONTAINS ACOUSTIC DATA IN BINARY INTEGER
```

```
C        FORMAT.  CONVERT TO BASE TEN FLOATING POINT
C             AND LOAD INTO THE Y MATRIX.
C    APPLY HANNING WINDOW FUNCTION TO DATA TO REDUCE SIDE-
C        LOBEING ASSOCIATED WITH RECTANGULAR TIME WINDOWS.
C
      DO 70 J=1,L,2
      RJ=J
      Y(J)=(IY(J)/2.0**23)*SIN(2.*PI*(RJ-1)/40956.)
   70 CONTINUE
C
C
      CALL STATS (FILE,Y,L,YMAX,YMIN,YMEAN,YSTDEV)
      CALL POWER (FILE,Y,L)
C
C        RETURN VALUES OF THE Y MATRIX ARE THE SPECTRUM
C          POWER COEFFICIENTS.
C        SET FL=LOWER FREQ LIMIT OF THE SEARCH WINDOW.
C        ISB=INTEGER NUMBER OF THE STARTING BIN OF THE
C          SEARCH WINDOW.
      FL=220.
      FU=FL+FLOAT(SRBW)
      ISB=(INT(FL*2*NREC))+1
C        LOAD THE YA MATRIX WITH THE SEARCH WINDOW POWER
C        COEFFICIENTS AND THE YL MATRIX WITH THE SEARCH
C                   WINDOW FREQUENCIES.   COMPUTE THE AVG
C        POWER IN THE WINDOW (YNOIS). THIS WILL BE
C          USED IN APPROXIMATING THE AMBIENT NOISE LEVEL.
C        SET DESIRED THRESHOLD AND CANCEL UNDESIRED NOISE
C        LEVEL. NOTE--VALUE OF PCT MUST BE SET SUCH THAT THRES
C        APPROXIMATES THE AMBIENT NOISE LEVEL.  IF
C        THE RATIO OF SIGNAL BINS TO NOISE BINS IN THE
C        SEARCH WINDOW IS LOW, SET PCT.GE.1.0 .  FOR
C        SMALL SEARCH WINDOWS AND/OR HIGH S/N RATIOS
C        PCT SHOULD BE LESS THAN 1.0 .
      PCT=1.0
      YNOIS=0.
C
      DO 80 I=1,N
      YL(I)=FLOAT((ISB-2)+I)/20.
      YA(I)=Y((ISB-1)+I)
      YNOIS=YNOIS+YA(I)/N
   80 CONTINUE
C
      THRES=PCT*YNOIS
C
      DO 90 J=1,N
      YA(J)=YA(J)-THRES
      IF (YA(J).LT.0) YA(J)=0.0
```

```
   90 CONTINUE
C
C        COMPUTED TIME OF DETECTED FTRK SET TO CENTER TIME OF
C        DATA USED IN COMPUTING THE TRANSFORM.
      TIME(JJ)=2.*FILE-FLOAT(NREC)
C
C        PRINT OUT THE WINDOW POWER COEFFICIENTS.
C
      WRITE (6,100)
  100 FORMAT ('0YA MATRIX VALUES--PWR SPECTRUM COEFFICIENTS ',
     1'IN SRBW--')
C     WRITE (6,110)
  110 FORMAT ('0TOP LINE FREQS AS LABELED. READ L TO R, .05HZ/
     1 BIN')
C     WRITE (6,120)
  120 FORMAT (5X,'FREQ',9(8X,'FREQ'))
C     WRITE (6,130) (YL(I),I=1,10)
  130 FORMAT (10(2X,F8.2,2X))
C     WRITE (6,140) (YA(I),I=1,N)
  140 FORMAT (10(2X,F10.8))
      WRITE (6,150) THRES
  150 FORMAT ('0',17X,'THRESHOLD VALUE COMPUTED =',F10.8,
     12X, 'FOR THIS TRANSFORM.')
C
C        FIND THE BIN WITH THE MAXIMUM POWER COEFFICIENT.
      ISTOP=N-1
      YTRK=YA(1)
      K=1
C
      DO 160 I=1,ISTOP
      IF (YA(I+1).LT.YTRK) GO TO 160
      YTRK=YA(I+1)
      K=I+1
  160 CONTINUE
C
C
C        IF MAX FOUND=ZERO, GO TO NEXT RECORD. THIS WOULD
C        OCCUR ONLY FOR VALUES OF PCT GREATER THAN ONE IN A
C        LOW  SIGNAL TO NOISE RATIO ENVIRONMENT.
      IF (YTRK.EQ.0) GO TO 400
C
C        K CONTAINS THE NUMBER OF THE BIN CONTAINING YTRK.
      KL=K-2
      KU=K+2
C
C        SET CENTER BIN OF TRACKING WINDOW =TBIN(JJ) AND
C        TRACKED FREQ = THE VALUE OF THE FREQ BIN CONTAINING
C        YTRK.
      TBIN(JJ)=K
```

```
      FTRK(JJ)=YL(K)
      YMAG(JJ)=YA(K)
      WRITE (6,170) JJ,TBIN(JJ)
  170 FORMAT ('0',17X,'TBIN(',I2,')=',I4,' COMPUTED BY MAIN PROGRAM.')
      WRITE (6,180) FILE,FL,FU
  180 FORMAT ('0',17X,'FILE',F6.1,2X,'LARGEST COEFFICIENT IN',F6.1,'HZ',
     1'  TO',F6.1,'HZ FREQUENCY BAND IS IN BIN K BELOW:')
C
C        IF MAX IS OCCURING NEAR LIMITS OF SRBW, DO NOT FILTER
      IF (KL.LT.1) GO TO 200
      IF (KU.GT.N) GO TO 200
C
C
      KL=K-1
      KU=K+1
      FTRK(JJ)=YL(K)+RESOL*((YA(K+1)-YA(K-1))/(YA(K-1)+YA(K)+YA(K+1)))
      WRITE (6,191) YL(K),JJ,TIME(JJ),JJ,FTRK(JJ),(YA(J) ,J=KL,KU)
  191 FORMAT ('0',17X,'3 BIN RESOLUTION TRACKING VALUES: CENTER BIN',
     1' FREQUENCY=',F8.2,'   TIME(',I2,')=',F7.1,/,35X,'      FTRK(',I2,')=
     2',F8.3,//,18X,' POWER COEFFICIENTS IN BINS (K-1)/K/(K+1) ARE:',
     34X,3(F10.8,2X))
C     WRITE (6,190) YL(K),(YA(J),J=KL,KU),JJ,FTRK(JJ),JJ,TIME(JJ)
  190 FORMAT ('03 BIN RESOLUTION TRACKING VALUES: FREQ=',F8.2,
     1'  POWER=',3(2X,F10.8),/,10X,'NEW FTRK(',I2,')=',F8.3,
     23X,'TIME(',I2,')=',F7.1)
      GO TO 220
C
  200 CONTINUE
      WRITE (6,210)
  210 FORMAT ('OMAX OCCURING NEAR LIMITS OF SRBW. RESET FL.')
      WRITE (6,190) YL(K),(YA(J),J=KL,KU),JJ,FTRK(JJ),JJ,TIME(JJ)
C
  220 CONTINUE
      IF (JJ.LT.2) GO TO 400
C
C
C        TRACKING WINDOW SECTION OF PROGRAM STARTS HERE.
C
C
      WRITE (6,230)
  230 FORMAT ('0',//,30X,'----TRACKING WINDOW CHECK----')
C
      THMIN=3.*THRES
C
C        MAXSF=MAX ALLOWED BINSHIFT OF THE TRACKED
C        SIGNAL FROM ITS VALUE IN THE LAST TRANSFORM.
C        BNSHF = BIN SHIFT
C
```

```
      MAXSF=10
      BNSHF=TBIN(JJ)-TBIN(JJ-1)
      INFG=0
      IR=TBIN(JJ-1)
      IF (BNSHF.GT.0) GO TO 240
C
      INFG=1
      BNSHF=-BNSHF
  240 IF (BNSHF.GT.MAXSF) GO TO 260
C
      IF (INFG.EQ.0) WRITE (6,250) BNSHF
  250 FORMAT ('0',17X,'MANUEVERING TARGET OR NOISE: DOPPLER SHIFT UP ',
     1I4,' BINS.')
C
      IFLAG=1
      IF (BNSHF.GT.1) GO TO 340
C
      GO TO 400
C
C
  260 WRITE (6,270) BNSHF
  270 FORMAT ('0',17X,'BIN SHIFT OF ',I4,' BINS. RECHECK TRACKED FREQ.')
C
C        CENTER BIN OF TRACKING WINDOW =     ITS VALUE IN THE
C         LAST TRANSFORM.   CHECK THE NEW POWER COEF-
C         FICIENTS FOR THE TRACKING WINDOW BINS.
C
C         FIND THE MAXIMUM POWER COEFFICIENT IN THE WINDOW.
      YMAX=YA(IR-10)
      IK=1
C
      DO 280 I=1,20
      IF (YA(IR-10+I).LT.YMAX) GO TO 280
      YMAX=YA(IR-10+I)
      IK=IR-10+I
  280 CONTINUE
C
C
C         IK CONTAINS THE NUMBER OF THE BIN CONTAINING THE
C         MAXIMUM FOUND.  IF NO SIGNAL FOUND, BRANCH TO STMT
C         320, RESET CENTER BIN TO ITS VALUE IN THE LAST
C         TRANSFORM AND RETURN.
      IF (YMAX.LE.THMIN) GO TO 320
C
C         SET FTRK AND TBIN VALUES BASED ON MAXIMUM FOUND.
      FTRK(JJ)=YL(IK)
      FMAX=YL(IK)
      TBIN(JJ)=IK
```

```
      YMAG(JJ)=YA(IK)
      WRITE (6,290) JJ,TBIN(JJ)
  290 FORMAT ('0',17X,'NEW CENTER BIN : RESET TBIN(',I2,') TO ',I4)
      BNSHF=TBIN(JJ)-TBIN(JJ-1)
      IF (BNSHF.LT.0) BNSHF=-BNSHF
C
      IFLAG=2
      IF (BNSHF.GT.1) GO TO 340
C
  300 IKL=IK-1
      IKU=IK+1
      FTRK(JJ)=YL(IK)+RESOL*((YA(IK+1)-YA(IK-1))/(YA(IK-1)+YA(IK)+YA(IK+
     11)))
C     WRITE (6,310) FMAX,(YA(J),J=IKL,IKU),JJ,FTRK(JJ),JJ,TIME(JJ),JJ,
C    1TBIN(JJ)
  310 FORMAT ('03 BIN RESOLUTION TRACKING VALUES: FREQ=',F8.2,
     1'  POWER=',3(2X,F10.8),/,10X,'NEW FTRK(',I2,')=',F8.3,
     23X,'TIME(',I2,')=',F7.1,2X,'TBIN(',I2,')=',I4)
      WRITE (6,311) FMAX,JJ,TIME(JJ),JJ,FTRK(JJ),(YA(J),J=IKL,IKU)
  311 FORMAT ('0',17X,'3 BIN RESOLUTION TRACKING VALUES: CENTER BIN',
     1' FREQUENCY=',F8.2,'  TIME(',I2,')=',F7.1,/,35X,'NEW FTRK(',I2,')=
     2',F8.3,//,18X,' POWER COEFFICIENTS IN BINS (K-1)/K/(K+1) ARE:',
     34X,3(F10.8,2X))
C
      GO TO 400
C
C
  320 WRITE (6,330)
  330 FORMAT ('0',17X,'SIGNAL FOUND IN TRACKING WINDOW IS BELOW',
     1' MINIMUM VALUE.  CONTACT LOST.')
      TBIN(JJ)=TBIN(JJ-1)
      FTRK(JJ)=FTRK(JJ-1)
      YMAG(JJ)=0.
      GO TO 400
C
C
  340 IPRINT=1
      WRITE (6,350)
  350 FORMAT ('0',17X,'**CHECKING POWER IN OLD CENTER BIN, TBIN(JJ-1).
     1IF SIGNIFICANT, IPRINT VALUE FOLLOWS.')
      IF (YA(IR).GT.YA(IR-1)) IPRINT=IPRINT+1
      IF (YA(IR).GT.YA(IR+1)) IPRINT=IPRINT+1
      IF (IPRINT.LT.2) GO TO (400,300), IFLAG
      WRITE (6,360) IPRINT
  360 FORMAT ('0',17X,'IPRINT=',I2,'  LAST CENTER BIN STILL ',
     1'SIGNIFICANT.  FURTHER CHECKS NEEDED.')
C
C        DOUBLE SIZE OF OLD SIGNAL FOR COMPARISON WITH NEW ONE
```

```
      A=2.*YA(IR)
C
C        NOTE--- INDEXING DIFFERENCES REQUIRE DIFFERENT
C        SECTIONS TO MAKE THE SAME TESTS OF SIGNIFICANCE.
      IF (IFLAG.EQ.2) GO TO 390
C
C        IS THE OLD SIGNAL AT LEAST HALF AS LARGE AS THE NEW.
C        IF NOT, CONSIDER NEW SIGNAL GOOD,GO TO NEXT TRANSFORM
      IF (A.LT.YA(K)) GO TO 400
C
C        IF NO BRANCH ABOVE, OLD SIGNAL NEEDS FURTHER CHECKS.
C        RESET OLD SIGNAL TO ITS ORIGINAL SIZE.
      A=A/2.
C        IS THE OLD SIGNAL LARGER THAN THMIN
      IF (A.GT.THMIN) GO TO 370
C        IF NOT, IS NEW SIGNAL LARGER THAN THMIN
      IF (YA(K).LT.THMIN) GO TO 320
      GO TO 400
C        OLD SIGNAL IS SIGNIFICANT AND WILL BE USED AS THE
C        TRACKED SIGNAL.  CHANGE INDEXING TO CONFORM TO
C        310 WRITE FORMAT.
  370 TBIN(JJ)=IR
      IK=IR
      YMAG(JJ)=YA(IR)
      FMAX=YL(IR)
      WRITE (6,380)
  380 FORMAT ('0',17X,'LAST CENTER BIN USED WITH NEW POWER ',
     1  'COEFFICIENTS. MODIFIED VALUES FOLLOW.')
      GO TO 300
C
C        STEPS IN THE FOLLOWING SEQUENCE ARE THE SAME LOGIC
C        AS ABOVE BETWEEN STATEMENTS 360 AND 370.
  390 IF (A.LT.YA(IK)) GO TO 300
      A=A/2.
      IF (A.GT.THMIN) GO TO 370
      IF (YA(IK).LT.THMIN) GO TO 320
      GO TO 300
C
C
C        TRACKING WINDOW SECTION ENDS HERE.
C
C
  400 CONTINUE
C
C        NSTRT VALUE CHANGED SO THE NEXT DATA READ IS
C        'DOWN TAPE' BY A SUITABLE CHOSEN AMOUNT OF TIME.
      NSTRT=21
      WRITE (6,410)
```

```
  41C FORMAT ('0',17X,'RUN COMPLETED FOR THIS FILE NUMBER.')
C          IF JJ IS LESS THAN NTFM, RETURN.
C
  420 CONTINUE
C
C      WRITE (6,430)
  430 FORMAT ('1PLOT OF FREQ VRS TIME TC SHOW DOPPLER SHIFT')
C      CALL PLOTP (TIME,FTRK,NTFM,0)
C      WRITE (6,440)
  440 FORMAT ('1PLOT OF POWER MAGNITUDE VRS TIME')
C      CALL PLOTP (TIME,YMAG,NTFM,0)
       WRITE (6,450)
  450 FORMAT ('0',17X,'END OF PROGRAM.')
       STOP
       END
C
C
C
       SUBROUTINE STATS (FILE,Y,L,YMAX,YMIN,YMEAN,YSTDEV)
C
       REAL Y(L)
    5 FORMAT ('1',///////////)
   10 FORMAT ('0',17X,'FILE ',F6.1,' STATISTICS:',10X,'MAX VALUE',6X
     1,'MIN VALUE',6X,'MEAN VALUE',6X,'STD DEV',/,18X
     2, 'BASED ON SAMPLE SIZE OF ',I5,4(2X,E13.6))
       YMAX=Y(1)
       YMIN=Y(1)
       YMEAN=Y(1)
       SSQUS=Y(1)**2
C
       DO 20 I=2,L
       IF (Y(I).GT.YMAX) YMAX=Y(I)
       IF (Y(I).LT.YMIN) YMIN=Y(I)
       YMEAN=YMEAN+Y(I)
       SSQUS=SSQUS+Y(I)**2
   20 CONTINUE
C
       YMEAN=YMEAN/FLOAT(L)
       YSTDEV=SQRT((SSQUS-FLOAT(L)*YMEAN*YMEAN)/FLCAT(L-1))
       WRITE (6,5)
       WRITE (6,10) FILE,L,YMAX,YMIN,YMEAN,YSTDEV
       RETURN
       END
C
C
C
       SUBROUTINE POWER (FILE,Y,L)
C
```

```
C     DESCRIPTION -
C       SUBROUTINE POWER FINDS THE FOURIER TRANSFORM OF THE DATA IN
C     ARRAY Y. FROM THE TRANSFORM THE POWER SPECTRUM IS COMPUTED.
C     THE FOURIER COEFFICIENTS ARE COMPUTED BY SUBROUTINE FFREAL AND
C     SUBROUTINE FFT: ALGORITHMS WRITTEN BY R. C. SINGLETON OF THE
C     STANFORD RESEARCH INSTITUTE.
C
C     NOTE: THIS SUBROUTINE ALTERS THE DATA PASSED TO IT.
C
      REAL XL(10),XI(10)
      REAL Y(L)
   10 FORMAT ('0',17X,'FILE ',F6.1,' - POWER SPECTRUM')
      N=L/2
      CALL FFREAL (FILE,Y,Y(2),N,+2)
C
      DO 20 I=1,N
      Y(I)=Y(2*I-1)**2+Y(2*I)**2
   20 CONTINUE
C
      WRITE (6,10) FILE
      RETURN
      END
C
C
C
COMMENT:  SUBROUTINE FFREAL
C
C     PARAMETERS -
C         FILE= A REAL VARIABLE INDENTIFYING THE CURRENT DATA FILE.
C               (FOR USER IDENTIFICATION PURPOSES ONLY.)
C         A   = A REAL ARRAY CONTAINING THE DATA TO BE TRANSFORMED.
C               ON RETURN, ARRAY A CONTAINS THE COSINE AND SINE CO-
C                  EFFICIENTS OF THE TRANSFORM FOR THE 1ST THROUGH THE
C                  NTH HARMONIC.
C         B   = THE ADDRESS OF THE SECOND ELEMENT OF ARRAY A; I.E. A(2).
C         N   = AN INTEGER VARIABLE EQUAL TO 1/2 THE SIZE OF ARRAY A.
C               ON RETURN, N MAY BE SLIGHTLY SMALLER THAN THE VALUE
C                  ORIGINALLY PASSED. (SEE SUBPROGRAM FFT.)
C         ISN = AN INTEGER OF VALUE +2 IF THE REAL TRANSFORM IS TO BE
C               PREFORMED; -2 IF THE INVERSE TRANSFORM IS DESIRED.
C
C     DESCRIPTION -
C       IF ISN=+2, SUBROUTINE FFREAL COMPUTES THE FOURIER TRANSFORM OF
C         2*N REAL DATA VALUES. THE COSINE AND SINE COEFFICIENTS
C         ALTERNATE AND ARE RETURNED IN ARRAY A. THE RESULTS ARE AUTO-
C         MATICALLY SCALED BY THE USUAL SCALE FACTOR OF 1/(2*N).
C       IF ISN=-2, SUBROUTINE FFREAL COMPUTES THE INVERSE FOURIER
C         TRANSFORM. IN THIS CASE THE SCALE FACTOR IS 1/2.
```

```
C        IN BOTH CASES, SUBROUTINE FFT IS CALLED TC PREFORM THE ACTUAL
C          TRANSFORM.
C
C     REFERENCE:
C      SINGLETON, R. C.,"ALGORITHM FOR MIXED RADIX FFT", IEEE TRANS-
C         ACTIONS CN AUDIO AND ELECTROACOUSTICS, VOL.AU-17, NO.2,
C         PP. 93-103, JUNE 1969.
C
      SUBROUTINE FFREAL (FILE,A,B,N,ISN)
      REAL A(1),B(1)
      REAL IM
   10 FORMAT ('0',17X,'FILE ',F6.1,' - FOURIER TRANSFORM')
      WRITE (6,10) FILE
      INC=IABS(ISN)
      SN=0.
      IF (ISN.LT.0) GO TO 40
      CALL FFT (FILE,A,B,N,ISN)
      CN=1.0
      NK=N*INC+2
      NH=NK/2
      SD=2.0*ATAN(1.0)/FLOAT(N)
      CD=2.0*SIN(SD)**2
      SD=SIN(SD+SD)
      A(NK-1)=A(1)
      B(NK-1)=B(1)
      SC=1./(2.*N)
C
   20 DC 30 J=1,NH,INC
      K=NK-J
      AA=A(J)+A(K)
      AB=A(J)-A(K)
      BA=B(J)+B(K)
      BB=B(J)-B(K)
      RE=CN*BA+SN*AB
      IM=SN*BA-CN*AB
      B(K)=(IM-BB)*SC
      B(J)=(IM+BB)*SC
      A(K)=(AA-RE)*SC
      A(J)=(AA+RE)*SC
      AA=CN-(CD*CN+SD*SN)
      SN=(SD*CN-CD*SN)+SN
      CN=0.5/(AA**2+SN**2)+0.5
      SN=CN*SN
   30 CN=AA
C
      IF (ISN.GT.0) RETURN
      CALL FFT (FILE,A,B,N,ISN)
      RETURN
```

```
   40 CN=-1.0
      NK=N*INC+2
      NH=NK/2
      SD=2.0*ATAN(1.0)/FLOAT(N)
      CD=2.0*SIN(SD)**2
      SD=SIN(SD+SD)
      SC=-SD
      SC=0.5
      GO TO 20
      END
C
C
C
COMMENT:  SUBROUTINE FFT
C
C     PARAMETERS -
C       FILE = A REAL VARIABLE INDENTIFYING THE CURRENT DATA FILE.
C              (FOR USER IDENTIFICATION PURPOSES ONLY.)
C       A    = A REAL ARRAY ORIGINALLY CONTAINING THE REAL COMPONENTS OF
C              THE DATA. ON RETURN, ARRAY A CONTAINS THE REAL COMPONENTS
C              OF THE FOURIER TRANSFORM; I.E. THE COSINE COEFFICIENTS.
C       B    = A REAL ARRAY ORIGINALLY CONTAINING THE IMAGINARY COMPON-
C              ENTS OF THE DATA. ON RETURN, ARRAY B CONTAINS THE IMAG-
C              INARY COMPONENTS OF THE FOURIER TRANSFORM; I.E. THE SINE
C              COEFFICIENTS.
C       N    = AN INTEGER VARIABLE EQUAL TO THE SIZE OF ARRAY A.
C              (SIZE OF ARRAY A = SIZE OF ARRAY B.)
C       ISN  : THE MAGNITUDE OF ISN DETERMINES THE STEP SIZE OF DATA IN
C              THE ARRAYS A AND B. THE SIGN OF ISN DETERMINES WHETHER
C              THE COMPLEX OR INVERSE TRANSFORM WILL BE PREFORMED.
C
C     DESCRIPTION -
C       SUBPROGRAM FFT COMPUTES THE SINGLE-VARIATE COMPLEX FOURIER
C     TRANSFORM COMPUTED IN PLACE USING A FIXED-RADIX FAST FOURIER
C     TRANSFORM BY R. C. SINGLETON *.
C       THE VALUE OF N MAY BE SLIGHTLY ALTERED BY THE SUBPROGRAM IN
C     ORDER THAT ITS PRIME FACTORS SATISFY CERTAIN CONDITIONS.
C       ARRAYS AT(MAXF), CK(MAXF), BT(MAXF), SK(MAXF), AND NP(MAXP)
C     ARE USED FOR TEMPORARY STORAGE.  IF THE AVAILABLE STORAGE
C     IS INSUFFICIENT, THE PROGRAM IS TERMINATED BY A STOP.
C     MAXF MUST BE .GE. THE MAXIMUM PRIME FACTOR OF N.
C     MAXP MUST BE .GT. THE NUMBER OF PRIME FACTORS OF N.
C     IN ADDITION, IF THE SQUARE-FREE PORTION K OF N HAS TWO OR
C     MORE PRIME FACTORS, THEN MAXP MUST BE .GE. K-1.
C       ARRAY STORAGE IN NFAC FOR A MAXIMUM OF 13 PRIME FACTORS OF N.
C       IF N HAS MORE THAN ONE SQUARE-FREE FACTOR, THE PRODUCT OF THE
C     SQUARE-FREE FACTORS MUST BE .LE. 210.
C     ARRAY STORAGE FOR MAXIMUM PRIME FACTOR OF 23.
```

```
C      REFERENCE:
C       SINGLETON, R. C.,"ALGORITHM FOR MIXED RADIX FFT", IEEE TRANS-
C          ACTIONS ON AUDIO AND ELECTROACOUSTICS, VOL.AU-17, NO.2,
C          PP. 93-103, JUNE 1969.
C
C
       SUBROUTINE FFT (FILE,A,B,N,ISN)
       REAL A(1),B(1)
       DIMENSION NFAC(13),NP(209)
       DIMENSION AT(23),CK(23),BT(23),SK(23)
       EQUIVALENCE (I,II)
C      SET NFAC TO ZERO
C
    10 DC 20 I=1,13
    20 NFAC(I)=0
C
C
       NTOT=N
       NSPAN=N
C   THE FOLLOWING TWO CONSTANTS SHOULD AGREE WITH THE ARRAY DIMENSIONS.
       MAXF=23
       MAXP=209
C
       IF (ISN.EQ.0) GO TO 680
       INC=ISN
       C72=0.30901699437494742
       S72=0.95105651629515357
       S120=0.86602540378443865
       RAD=6.2831853071796
       IF (ISN.GE.0) GO TO 30
       S72=-S72
       S120=-S120
       RAD=-RAD
       INC=-INC
    30 NT=INC*NTOT
       KS=INC*NSPAN
       KSPAN=KS
       NN=NT-INC
       JC=KS/N
       RADF=RAD*FLOAT(JC)*0.5
       I=0
       JF=0
C
C   DETERMINE THE FACTORS OF N
C
       M=0
       K=N
       GC TO 50
```

```
   40 M=M+1
      NFAC(M)=4
      K=K/16
   50 IF (K-(K/16)*16.EQ.0) GO TO 40
      J=3
      JJ=9
      GO TO 70
   60 M=M+1
      NFAC(M)=J
      K=K/JJ
   70 IF (MOD(K,JJ).EQ.0) GO TO 60
      J=J+2
      JJ=J**2
      IF (JJ.LE.K) GO TO 70
      IF (K.GT.4) GO TO 80
      KT=M
      NFAC(M+1)=K
      IF (K.NE.1) M=M+1
      GO TO 120
   80 IF (K-(K/4)*4.NE.0) GO TO 90
      M=M+1
      NFAC(M)=2
      K=K/4
   90 KT=M
      J=2
  100 IF (MOD(K,J).NE.0) GO TO 110
      M=M+1
      NFAC(M)=J
      K=K/J
  110 J=((J+1)/2)*2+1
      IF (J.LE.K) GO TO 100
  120 IF (KT.EQ.0) GO TO 140
      J=KT
  130 M=M+1
      NFAC(M)=NFAC(J)
      J=J-1
      IF (J.NE.0) GO TO 130
C
  140 DO 150 III=1,13
      IF (NFAC(III).GT.MAXF) GO TO 630
  150 CONTINUE
C
      NPROD=NFAC(1)
C
      DO 170 III=2,13
      IF (NFAC(III).LT.1) GO TO 180
      IIII=III-1
C
```

```
      DO 160 KKK=1,IIII
      IF (NFAC(III).EQ.NFAC(KKK)) GO TO 170
  160 CONTINUE
C
      NPROD=NPROD*NFAC(III)
  170 CONTINUE
C
  180 NPROD=NPROD-1
      IF (NPROD.GT.MAXP) GO TO 630
      WRITE (6,190) FILE,N,NFAC
  190 FORMAT ('0',17X,'FILE ',F6.1,' IN FFT.',4X,I5,' TERMS',/,
     1 28X,'FACTORS:'/28X,13I5)
C
C  COMPUTE FOURIER TRANSFORM
C
  200 SD=RADF/FLOAT(KSPAN)
      CD=2.0*SIN(SD)**2
      SD=SIN(SD+SD)
      KK=1
      I=I+1
      IF (NFAC(I).NE.2) GO TO 250
C
C  TRANSFORM FOR FACTOR OF 2 (INCLUDING ROTATION FACTOR)
C
      KSPAN=KSPAN/2
      K1=KSPAN+2
  210 K2=KK+KSPAN
      AK=A(K2)
      BK=B(K2)
      A(K2)=A(KK)-AK
      B(K2)=B(KK)-BK
      A(KK)=A(KK)+AK
      B(KK)=B(KK)+BK
      KK=K2+KSPAN
      IF (KK.LE.NN) GO TO 210
      KK=KK-NN
      IF (KK.LE.JC) GO TO 210
      IF (KK.GT.KSPAN) GO TO 440
  220 C1=1.0-CD
      S1=SD
  230 K2=KK+KSPAN
      AK=A(KK)-A(K2)
      BK=B(KK)-B(K2)
      A(KK)=A(KK)+A(K2)
      B(KK)=B(KK)+B(K2)
      A(K2)=C1*AK-S1*BK
      B(K2)=S1*AK+C1*BK
      KK=K2+KSPAN
```

```
      IF (KK.LT.NT) GO TO 230
      K2=KK-NT
      C1=-C1
      KK=K1-K2
      IF (KK.GT.K2) GO TO 230
      AK=CD*C1+SD*S1
      S1=(SD*C1-CD*S1)+S1
      C1=C1-AK
      KK=KK+JC
      IF (KK.LT.K2) GO TO 230
      K1=K1+INC+INC
      KK=(K1-KSPAN)/2+JC
      IF (KK.LE.JC+JC) GO TO 220
      GO TO 200
C
C  TRANSFORM FOR FACTOR OF 3 (OPTIONAL CODE)
C
  240 K1=KK+KSPAN
      K2=K1+KSPAN
      AK=A(KK)
      BK=B(KK)
      AJ=A(K1)+A(K2)
      BJ=B(K1)+B(K2)
      A(KK)=AK+AJ
      B(KK)=BK+BJ
      AK=-0.5*AJ+AK
      BK=-0.5*BJ+BK
      AJ=(A(K1)-A(K2))*S120
      BJ=(B(K1)-B(K2))*S120
      A(K1)=AK-BJ
      B(K1)=BK+AJ
      A(K2)=AK+BJ
      B(K2)=BK-AJ
      KK=K2+KSPAN
      IF (KK.LT.NN) GO TO 240
      KK=KK-NN
      IF (KK.LE.KSPAN) GO TO 240
      GO TO 400
C
C  TRANSFORM FOR FACTOR OF 4
C
  250 IF (NFAC(I).NE.4) GO TO 340
      KSPNN=KSPAN
      KSPAN=KSPAN/4
  260 C1=1.0
      S1=0
  270 K1=KK+KSPAN
      K2=K1+KSPAN
```

```
      K3=K2+KSPAN
      AKP=A(KK)+A(K2)
      AKM=A(KK)-A(K2)
      AJP=A(K1)+A(K3)
      AJM=A(K1)-A(K3)
      A(KK)=AKP+AJP
      AJP=AKP-AJP
      BKP=B(KK)+B(K2)
      BKM=B(KK)-B(K2)
      BJP=B(K1)+B(K3)
      BJM=B(K1)-B(K3)
      B(KK)=BKP+BJP
      BJP=BKP-BJP
      IF (ISN.LT.0) GO TO 300
      AKP=AKM-BJM
      AKM=AKM+BJM
      BKP=BKM+AJM
      BKM=BKM-AJM
      IF (S1.EQ.0) GO TO 310
  280 A(K1)=AKP*C1-BKP*S1
      B(K1)=AKP*S1+BKP*C1
      A(K2)=AJP*C2-BJP*S2
      B(K2)=AJP*S2+BJP*C2
      A(K3)=AKM*C3-BKM*S3
      B(K3)=AKM*S3+BKM*C3
      KK=K3+KSPAN
      IF (KK.LE.NT) GO TO 270
  290 C2=CD*C1+SD*S1
      S1=(SD*C1-CD*S1)+S1
      C1=C1-C2
      C2=C1**2-S1**2
      S2=2.0*C1*S1
      C3=C2*C1-S2*S1
      S3=C2*S1+S2*C1
      KK=KK-NT+JC
      IF (KK.LE.KSPAN) GO TO 270
      KK=KK-KSPAN+INC
      IF (KK.LE.JC) GO TO 260
      IF (KSPAN.EQ.JC) GO TO 440
      GO TO 200
  300 AKP=AKM+BJM
      AKM=AKM-BJM
      BKP=BKM-AJM
      BKM=BKM+AJM
      IF (S1.NE.0) GO TO 280
  310 A(K1)=AKP
      B(K1)=BKP
      A(K2)=AJP
```

```
      B(K2)=BJP
      A(K3)=AKM
      B(K3)=BKM
      KK=K3+KSPAN
      IF (KK.LE.NT) GO TO 270
      GO TO 290
C
C  TRANSFORM FOR FACTOR OF 5 (OPTIONAL CODE)
C
  320 C2=C72**2-S72**2
      S2=2.0*C72*S72
  330 K1=KK+KSPAN
      K2=K1+KSPAN
      K3=K2+KSPAN
      K4=K3+KSPAN
      AKP=A(K1)+A(K4)
      AKM=A(K1)-A(K4)
      BKP=B(K1)+B(K4)
      BKM=B(K1)-B(K4)
      AJP=A(K2)+A(K3)
      AJM=A(K2)-A(K3)
      BJP=B(K2)+B(K3)
      BJM=B(K2)-B(K3)
      AA=A(KK)
      BB=B(KK)
      A(KK)=AA+AKP+AJP
      B(KK)=BB+BKP+BJP
      AK=AKP*C72+AJP*C2+AA
      BK=BKP*C72+BJP*C2+BB
      AJ=AKM*S72+AJM*S2
      BJ=BKM*S72+BJM*S2
      A(K1)=AK-BJ
      A(K4)=AK+BJ
      B(K1)=BK+AJ
      B(K4)=BK-AJ
      AK=AKP*C2+AJP*C72+AA
      BK=BKP*C2+BJP*C72+BB
      AJ=AKM*S2-AJM*S72
      BJ=BKM*S2-BJM*S72
      A(K2)=AK-BJ
      A(K3)=AK+BJ
      B(K2)=BK+AJ
      B(K3)=BK-AJ
      KK=K4+KSPAN
      IF (KK.LT.NN) GO TO 330
      KK=KK-NN
      IF (KK.LE.KSPAN) GO TO 330
      GO TO 400
```

```
C
C     TRANSFORM FOR ODD FACTORS
C
  340 K=NFAC(I)
      KSPNN=KSPAN
      KSPAN=KSPAN/K
      IF (K.EQ.3) GO TO 240
      IF (K.EQ.5) GO TO 320
      IF (K.EQ.JF) GO TO 360
      JF=K
      S1=RAD/FLOAT(K)
      C1=COS(S1)
      S1=SIN(S1)
      IF (JF.GT.MAXF) GO TO 640
      CK(JF)=1.0
      SK(JF)=0.0
      J=1
  350 CK(J)=CK(K)*C1+SK(K)*S1
      SK(J)=CK(K)*S1-SK(K)*C1
      K=K-1
      CK(K)=CK(J)
      SK(K)=-SK(J)
      J=J+1
      IF (J.LT.K) GO TO 350
  360 K1=KK
      K2=KK+KSPNN
      AA=A(KK)
      BB=B(KK)
      AK=AA
      BK=BB
      J=1
      K1=K1+KSPAN
  370 K2=K2-KSPAN
      J=J+1
      AT(J)=A(K1)+A(K2)
      AK=AT(J)+AK
      BT(J)=B(K1)+B(K2)
      BK=BT(J)+BK
      J=J+1
      AT(J)=A(K1)-A(K2)
      BT(J)=B(K1)-B(K2)
      K1=K1+KSPAN
      IF (K1.LT.K2) GO TO 370
      A(KK)=AK
      B(KK)=BK
      K1=KK
      K2=KK+KSPNN
      J=1
```

```
  380 K1=K1+KSPAN
      K2=K2-KSPAN
      JJ=J
      AK=AA
      BK=BB
      AJ=0.0
      BJ=0.0
      K=1
  390 K=K+1
      AK=AT(K)*CK(JJ)+AK
      BK=BT(K)*CK(JJ)+BK
      K=K+1
      AJ=AT(K)*SK(JJ)+AJ
      BJ=BT(K)*SK(JJ)+BJ
      JJ=JJ+J
      IF (JJ.GT.JF) JJ=JJ-JF
      IF (K.LT.JF) GO TO 390
      K=JF-J
      A(K1)=AK-BJ
      B(K1)=BK+AJ
      A(K2)=AK+BJ
      B(K2)=BK-AJ
      J=J+1
      IF (J.LT.K) GO TO 380
      KK=KK+KSPNN
      IF (KK.LE.NN) GO TO 360
      KK=KK-NN
      IF (KK.LE.KSPAN) GO TO 360
C
C MULTIPLY BY ROTATION FACTOR (EXCEPT FOR FACTORS OF 2 AND 4)
C
  400 IF (I.EQ.M) GO TO 440
      KK=JC+1
  410 C2=1.0-CD
      S1=SD
  420 C1=C2
      S2=S1
      KK=KK+KSPAN
  430 AK=A(KK)
      A(KK)=C2*AK-S2*B(KK)
      B(KK)=S2*AK+C2*B(KK)
      KK=KK+KSPNN
      IF (KK.LE.NT) GO TO 430
      AK=S1*S2
      S2=S1*C2+C1*S2
      C2=C1*C2-AK
      KK=KK-NT+KSPAN
      IF (KK.LE.KSPNN) GO TO 430
```

```
      C2=C1-(CD*C1+SD*S1)
      S1=S1+(SD*C1-CD*S1)
      KK=KK-KSPNN+JC
      IF (KK.LE.KSPAN) GO TO 420
      KK=KK-KSPAN+JC+INC
      IF (KK.LE.JC+JC) GO TO 410
      GO TO 200
C
C  PERMUTE THE RESULTS TO NORMAL ORDER---DONE IN TWO STAGES
C  PERMUTATION FOR SQUARE FACTORS OF N
C
  440 NP(1)=KS
      IF (KT.EQ.0) GO TO 490
      K=KT+KT+1
      IF (M.LT.K) K=K-1
      J=1
      NP(K+1)=JC
  450 NP(J+1)=NP(J)/NFAC(J)
      NP(K)=NP(K+1)*NFAC(J)
      J=J+1
      K=K-1
      IF (J.LT.K) GO TO 450
      K3=NP(K+1)
      KSPAN=NP(2)
      KK=JC+1
      K2=KSPAN+1
      J=1
C
C  PERMUTATION FOR SINGLE-VARIATE TRANSFORM (OPTICNAL CODE)
C
  460 AK=A(KK)
      A(KK)=A(K2)
      A(K2)=AK
      BK=B(KK)
      B(KK)=B(K2)
      B(K2)=BK
      KK=KK+INC
      K2=KSPAN+K2
      IF (K2.LT.KS) GO TO 460
  470 K2=K2-NP(J)
      J=J+1
      K2=NP(J+1)+K2
      IF (K2.GT.NP(J)) GO TO 470
      J=1
  480 IF (KK.LT.K2) GO TO 460
      KK=KK+INC
      K2=KSPAN+K2
      IF (K2.LT.KS) GO TO 480
```

```
      IF (KK.LT.KS) GO TO 470
      JC=K3
  490 IF (2*KT+1.GE.M) RETURN
      KSPNN=NP(KT+1)
C
C  PERMUTATION FOR SQUARE-FREE FACTORS OF N
C
      J=M-KT
      NFAC(J+1)=1
  500 NFAC(J)=NFAC(J)*NFAC(J+1)
      J=J-1
      IF (J.NE.KT) GO TO 500
      KT=KT+1
      NN=NFAC(KT)-1
      IF (NN.GT.MAXP) GO TO 660
      JJ=0
      J=0
      GO TO 530
  510 JJ=JJ-K2
      K2=KK
      K=K+1
      KK=NFAC(K)
  520 JJ=KK+JJ
      IF (JJ.GE.K2) GO TO 510
      NP(J)=JJ
  530 K2=NFAC(KT)
      K=KT+1
      KK=NFAC(K)
      J=J+1
      IF (J.LE.NN) GO TO 520
C
C
      J=0
      GO TO 550
  540 K=KK
      KK=NP(K)
      NP(K)=-KK
      IF (KK.NE.J) GO TO 540
      K3=KK
  550 J=J+1
      KK=NP(J)
      IF (KK.LT.0) GO TO 550
      IF (KK.NE.J) GO TO 540
      NP(J)=-J
      IF (J.NE.NN) GO TO 550
      MAXF=INC*MAXF
C
C  RECRDER A AND B, FOLLOWING THE PERMUTATION CYCLES
```

```
C
      GC TO 620
  560 J=J-1
      IF (NP(J).LT.0) GO TO 560
      JJ=JC
  570 KSPAN=JJ
      IF (JJ.GT.MAXF) KSPAN=MAXF
      JJ=JJ-KSPAN
      K=NP(J)
      KK=JC*K+II+JJ
      K1=KK+KSPAN
      K2=0
  580 K2=K2+1
      AT(K2)=A(K1)
      BT(K2)=B(K1)
      K1=K1-INC
      IF (K1.NE.KK) GO TO 580
  590 K1=KK+KSPAN
      K2=K1-JC*(K+NP(K))
      K=-NP(K)
  600 A(K1)=A(K2)
      B(K1)=B(K2)
      K1=K1-INC
      K2=K2-INC
      IF (K1.NE.KK) GO TO 600
      KK=K2
      IF (K.NE.J) GO TO 590
      K1=KK+KSPAN
      K2=0
  610 K2=K2+1
      A(K1)=AT(K2)
      B(K1)=BT(K2)
      K1=K1-INC
      IF (K1.NE.KK) GO TO 610
      IF (JJ.NE.0) GO TO 570
      IF (J.NE.1) GO TO 560
  620 J=K3+1
      NT=NT-KSPNN
      II=NT-INC+1
      IF (NT.GE.0) GO TO 560
C
C
      RETURN
C
  630 N=N-1
      GC TO 10
C
  640 WRITE (6,650)
```

```
  650 FORMAT ('   *** ERROR ***  MAX PRIME FACTOR EXCEEDED')
      STOP
C
  660 WRITE (6,670)
  670 FORMAT ('   *** ERROR ***  MAX PRODUCT OF SQUARE FREE VALUES EXCEED
     1ED')
      STOP
C
  680 WRITE (6,690)
  690 FORMAT ('   *** ERROR *** ISN CANNOT BE ZERO')
      STOP
      END
```

```
C
X-Y TRACKING FILTER PROGRAM DEVELOPED BY LT. G. W. MITSCHANG.
C
//  EXEC  FORTCLG,REGION.FORT=170K,REGION.GO=100K
//FORT.SYSIN  DD  *
      DIMENSION R(6,100),FD(6,100),BR(6,100),FDDOT(6,100),XS(100),
     1X(6),Y(6),VR(6),VRDOT(6),T(100),YS(100),RERROR(100),YTAR(100),
     2Z(100,5),VVS(3),THS1(100),THS2(100),XTAR(100),TH2(2),ARX(2)
      DIMENSION XCUR(5),XPRED(5),XFIL(5),ZNOIS(16),COV(25),PHI(25),
     1PHITR(25),HOB(20),HOBTR(20),QEXIT(25),GAIN(20),COVK(25),
     2TEMP2(20),TEMP3(20),TEMP4(25),TEMP5(25),GAINTR(20),BERROR(100)
      DIMENSION SUBX(10),SUBY(10),SUBVEL(10),SUBHD(10),TEMP1(20)
      DIMENSION FOO(100),XYSQ(4),LT(4),WM(4),F(4),XINT(2),YINT(2)
      DIMENSION XMC(5,20),XVAR(5,20),XMN(20),YMN(20),XSTD(5,20)
      DIMENSION XYVAR(5,20),RXY(20),XYA(20),RVXVY(20),VXVYA(20)
      DIMENSION GA(20),ZHOLD(20)
      COMMON FQ,VP,FO,PI,RAD
      RNG(VQ,DTH,THES,AVET) = (ADELT*VQ/DTH)*SIN(THES - AVET)
      FCIT(VQ,THES,AVET) = FAVE*(1. + (VQ/VP)*COS(THES - AVET))
C
C
   59 FORMAT('1    SIMULATED OBSERVATIONS'///3X,'TIME',15X,'TRUE',16X,
     1'NOISE',18X,'MEASUREMENT'//)
   60 FORMAT('0',F7.1,4X,'BEARING',F10.3,6X,'+',6X,F7.3,6X,'=',9X,F10.3)
   61 FORMAT('0',11X,'FREQ',3X,F10.3,6X,'+',6X,F7.3,6X,'=',9X,F10.3)
   62 FORMAT('0',10X,I4,'  SENSORS USED')
   63 FORMAT('1    RANGE AND HEADING FORMULA'//)
   64 FORMAT('0  TIME =',F7.2,5X,'BEARING =',F8.2,5X,'RANGE =',F10.2,
     15X,'TRUE RANGE =',F10.2/)
   65 FORMAT('0',10X,'SPEED =',F5.2,' KNOTS',5X,'ANGLES',2F10.3,5X,
     1'POSSIBLE HEADINGS',2F10.3/)
   66 FORMAT(//83X,'BR NOISE MEAN',F10.3//80X,'BR NOISE STD DEV',F10.3)
   99 FORMAT('1 TRUE BUOY DATA')
  100 FORMAT('0',//20X,'BOUY',I3,'  DATA',5X,'LOCATION    X  =',F9.1,3X,
     1'Y  =',F9.1,////5X,'TIME',8X,'RANGE',9X,'BEARING',8X,'DOPPLER',
     24X,'RATE OF DOPPLER',5X,'X(SUB)',8X,'Y(SUB)'//)
  300 FORMAT(1X,F8.1,3F15.4,E15.4,2F15.4)
  330 FORMAT('1       PLOT OF SUBMARINE TRACK AND BOUY LOCATIONS'///,'
     1    COORDINATES IN YARDS'//)
  400 FORMAT('0    SUB SPEED IS',F6.2,' KNOTS     HEADING IS',F8.2//)
  401 FORMAT('0  INITIAL GUESSES',//2X,'REST FREQ',F10.2,4X,'MED VEL',
     1F10.2,4X,'SUB VEL',F10.2//)
  668 FORMAT('0 ASINE =',F10.6)
  700 FORMAT('1   MONTE CARLO PLOT BASED ON',I10,'  RUNS'//)
  701 FORMAT('1  MONTE CARLO STATISTICS ON',I10,'  RUNS'///4X,'TIME POIN
     1T',16X,'X',15X,'VX',14X,'Y',15X,'VY',12X,'FC'//)
  702 FORMAT('0',I10,10X,5F15.3)
  703 FORMAT('0  VARIANCE',10X,5F15.3)
```

```
  704 FORMAT('0  STD DEV',11X,5F15.3/)
  705 FORMAT('0  COVARIANCE',8X,2F15.3)
  706 FORMAT('0  CORR COEF',9X,2F15.3/)
  707 FORMAT('0  TILT ANGLE',8X,F15.3,15X,F15.3)
708   FORMAT ('OXINT',F10.3,'     YINT',F10.3)
  709 FORMAT('0         NEW VARIANCES',4F15.3)
  710 FORMAT('0         NEW STD DEV  ',4F15.3//)
  712 FORMAT('0  AVERAGE START-UP TIME IS',F10.2)
  715 FORMAT('0 COVARIANCE TERMS XX',F10.5,'  XY',F10.5,' YY',F10.5)
  716 FORMAT('0  COV TILT',F10.2,'   NEW VARIANCES',2F10.3//37X,F10.3)
 1000 FORMAT('0',////,30X,'TIME = ',F7.1/)
 1001 FORMAT('   PHI MATRIX'//(3X,5F10.3/))
 1020 FORMAT('0  HOB MATRIX'//(3X,5F15.7/))
 1039 FORMAT('0   GAIN MATRIX')
 1040 FORMAT(5X,/5F15.3)
 1050 FORMAT('0  EXCITATION MATRIX'//(3X,5F15.3/))
 1058 FORMAT('0      ZNJIS MATRIX')
 1059 FORMAT(5X,/5F15.8)
 1060 FORMAT('0  PREDICTED COVARIANCE MATRIX'//(3X,5F15.3/))
 1061 FORMAT('0  INITIAL COVARIANCE MATRIX'//(3X,5F15.3/))
 1070 FORMAT('0  UPDATED COVARIANCE MATRIX'//(3X,5F15.3/))
 1080 FORMAT('0',25X,'X',14X,'VX',13X,'Y',14X,'VY',14X,'FO'//
     1'   CURRENT VALUE',5F15.3//' PREDICTED VALUE',5F15.3//' FILTERED
     2VALUE',5F15.3)
 1081 FORMAT('0      TRUE VALUE',5F15.3//)
 1082 FORMAT('0 FILTERED SPEED  =',F10.2,5X,'FILTERED HEADING  =',F10.2)
 1091 FORMAT('0',25X,'FILT RANGE',F15.2,10X,'FILT BEARING',F15.2,//25X,
     1'TRUE RANGE',F15.2,10X,'TRUE BEARING',F15.2)
 1092 FORMAT('0  FINAL FILTER VALUES ',///25X,'X',14X,'VX',13X,'Y',14X,
     1'VY',14X,'FO'//)
 1093 FORMAT(16X,5F15.3,5X,'IRE  =',I6)
 1100 FORMAT('0',10X,'INITIAL RANGE',F10.2,10X,'TRUE RANGE',F10.2//10X,
     1'INITIAL X VEL',F10.2,10X,'TRUE X VEL',F10.2//10X,'INITIAL Y VEL',
     2F10.2,10X,'TRUE Y VEL',F10.2)
 1101 FORMAT('0 TIME',F10.3,10X,'BEARING',F10.3,10X,'THETA - THTAS',
     1F10.3,10X,'HEADING',F10.3,5X,'FO  =',F12.2/)
 1102 FORMAT('0  XINT =',F15.2,10X,'YINT =',F15.2)
 2000 FORMAT('0   PRED BEARING',F15.2,10X,'PRED FREQ1',F15.3,10X,
     1'PRED FREQ2',F15.3,10X,'PRED FREQ3',F15.3)
 2010 FORMAT('0   MEAS BEARING',F15.2,10X,'MEAS FREQ1',F15.3,10X,
     1'MEAS FREQ2',F15.3,10X,'MEAS FREQ3',F15.3)
 2011 FORMAT('0  RESIDUALS  -      ANGLE',F10.2,10X,'FREQ1',F10.3,10X,
     1'FREQ2',F10.3,10X,'FREQ3',F10.3)
 5000 FORMAT(F10.8)
 5001 FORMAT('0  SIGMA2 =    ',F10.8)
 5002 FORMAT(I2)
 5003 FORMAT(10X,F10.2)
 5004 FORMAT(2I10)
```

```
5005 FORMAT(//2I10)
6000 FORMAT(I4)
6001 FORMAT(4F10.2)
6002 FORMAT('0 NUMBER OF RUNS PER TRACK  = ',I6//)
6003 FORMAT('0 NUMBER OF TRACKS  = ',I6//)
8000 FORMAT('0  ANGLE NOISE STD DEV IS',F8.2)
9010 FORMAT('0  DETERMINENT ',E15.7)
C
  666 FORMAT('0 KJ =',I4,5X,'Z(KJ,1) =',F10.3,5X,'Z(1,1) =',F10.3,
     15X,'ADELTH =',F10.3)
  667 FORMAT('0 TIME KJ =',F10.2,5X,'Z(KJ,2) =',F10.2,5X,'Z(1,2) =',
     1F10.2,5X,'ADELF =',F10.2,5X,'ATHETH =',F10.2)
  711 FORMAT('0  INITIAL VELOCITY GUESS IN KNOTS',F8.1)
5010  FORMAT ('OT(',I2,')=',F10.2)
9990  FORMAT ('OSUBHD(',I2,')=',F6.1)
      PI = 3.14159
      RAD = 57.29578
C
C    IXA AND IXF ARE STARTING NUMBERS FOR RANDOM NUMBER SUBROUTINE.
C
      IXA=452323
      IXF=986521
C
C    NSPCT IS THE NUMBER OF SEPERATE TRACKS TO BE RUN.  SUBX, SUBY,
C      SUBVEL, AND SUBHD ARE  STARTING POSITION OF TARGET, VELOCITY AND
C     HEADING FOR THE TRACK.
C
      NSPCT=1
C
C     JJQQ IS THE NUMBER OF SIMULATIONS PER TRACK.
C
      JJQQ=100
C
C
C
C    FO IS ONLY USED TO DECIDE UP OR DOWN DOPPLER FOR HEADING CALCULATION
      FO=233.5
      WRITE (6,9959) FO
9959  FORMAT ('OFO=',F8.3)
C
C    INITIAL ESTIMATE AT TARGET VELOCITY IS AVSK,  IN KNOTS.
      AVSK=2.
C
C     BEARING STANDARD DEVIATION IS  5 DEGREES
C
      SA=30.
C
C
```

```
C     FREQUENCY STANDARD DEVIATION IS   .025HZ
      SF = .025
C
C
      READ(5,6001) (SUBX(I),SUBY(I),SUBVEL(I),SUBHD(I),I=1,NSPOT)
C     DO 204  JZA=1,5
      JZA=1
      WRITE(6,5005) IXA,IXF
      WRITE(6,6003) NSPOT
      WRITE(6,6001) (SUBX(I),SUBY(I),SUBVEL(I),SUBHD(I),I=1,NSPOT)
      IJK=1
      WRITE (6,9990) (J,SUBHD(J),J=1,IJK)
      WRITE(6,6002) JJQQ
C    TIME IS IN SECONDS
C
C    NUMBER OF TIME POINTS IS NUM
C
      NUM=17
      TINT=60.
      DATA X(1),X(2),X(3),X(4),X(5)/0.,0.,0.,-1200.,3000./
      DATA Y(1),Y(2),Y(3),Y(4),Y(5)/0.,0.,0.,-1800.,2400./
      T(1)=190.
      DO 9 KL=2,NUM
    9 T(KL) = T(KL-1) + TINT
      WRITE(6,5010)      (I,T(I),I=1,NUM)
C
      NUM1 = NUM + 1
C      THE SENSORS ARE POSITIONED AT X(I), Y(I).
C
C
C    INITIAL SUB POSITION    XSO,YSO
C
C   SUB SPEED AND DIRECTION ARE VSS AND THTA
C
C     XSO = SUBX(NS)
      XSO = SUBX(1)
C     YSO = SUBY(NS)
      YSO = SUBY(1)
C     VSS = SUBVEL(NS)
      VSS = SUBVEL(1)
      TC = T(1)
      XS(1)=XSO
      YS(1)=YSO
C
      NUMA=1
      DO 9991 NS=1,IJK
C     THTA = SUBHD(NS)
      THTA = SUBHD(1)
```

```
C
C       CONVERT FROM DEGREES TO RADIANS
      THTAS = THTA/57.29578
C
C       CONVERT FROM KNOTS TO YARDS PER SECOND
      VS = VSS*.563
C
      FREQ = 233.85
      VMED = 1625.5
C
C     NUMBER OF OBSERVATION VARIABLES IS M.
C     THIS DETERMINES THE NUMBER OF ROWS OF HOB.
C
      M=2
      M1 = M - 1
      M2 = M*5
      MM = M*M
C
C     WRITE(6,62) M1
C
      DO 1 I=NUMA,NUM
      XS(I) = XSO + VS*COS(THTAS)*(T(I) - TO)
      YS(I) = YSO + VS*SIN(THTAS)*(T(I) - TO)
C
C    LOOP FOR EACH HYDROPHONE
C
      DO 2 J=1,M1
      R(J,I) = ((XS(I) - X(J))**2 + (YS(I) - Y(J))**2)**.5
      BR(J,I) = ATAN((YS(I) -Y(J))/(XS(I) - X(J)))
      IF((XS(I) - X(J)).GE.0.0) GO TO 5
      IF((YS(I) - Y(J)).GE.0.0) BR(J,I) = BR(J,I) + 3.14159
      IF((YS(I) - Y(J)).LT.0.0) BR(J,I) = BR(J,I) - 3.14159
    5 CONTINUE
      VR(J) = VS*COS(THTAS - BR(J,I))
      FD(J,I) = FREQ/(1. + VR(J)/VMED)
      VRDOT(J) = -(VS*SIN(THTAS - BR(J,I)))**2/R(J,I)
      FDDOT(J,I) = (FD(J,I)*FD(J,I)*VRDOT(J))/(FREQ*VMED)
C
C     CONVERT FROM RADIANS TO DEGREES FOR OUTPUT
      BR(J,I) = BR(J,I)*57.29578
    2 CONTINUE
      XSO = XS(I)
      YSO = YS(I)
      TO = T(I)
      IF (I.LT.NUM) GO TO 1
      XSO=XS(NUMA)
      YSO=YS(NUMA)
      TO=T(NUMA)
```

```
      IF (NS.EQ.IJK) TO = T(1)
    1 CONTINUE
 9991 CONTINUE
C
C    CUTPUT STATEMENTS FOR BUOYS.  REMCVE COMMENT SYMBCL AS DESIRED.
C
C     WRITE(6,99)
      DC 4 L=1,M1
C     WRITE(6,100) L,X(L),Y(L)
      DC 4 K=1,NUM
C     WRITE(6,300) T(K),R(L,K),BR(L,K),FD(L,K),FDDOT(L,K),XS(K),YS(K)
    4 CCNTINUE
C
C
C     SET OF PARAMETERS FOR CALL GAUSS SUBROUTINE
C
C
C
      WRITE(6,8000) SA
      AMA = 0.
C
      AMF = 0.
      DC 398 IY=1,20
      ZHOLD(IY)=0.
      DO 399 IX=1,5
      XMC(IX,IY) = 0.
      XYVAR(IX,IY) = 0.
  399 XVAR(IX,IY) = 0.
      XMN(IY) = 0.
      YMN(IY) = 0.
  398 CONTINUE
      XINT(2) = 0.
      YINT(2) = 0.
      XINVE = 0.
      YINVE = 0.
      DC 397 JJ=1,20
      FXY(JJ) = 0.
      XYA(JJ) = 0.
      RVXVY(JJ) = 0.
      VXVYA(JJ) = 0.
  397 CONTINUE
      AVKJ = 0.
      WRITE(6,400) VSS,THTA
      WRITE(6,711) AVSK
C    THIS DO LOCP RUNS JJQQ SIMULATIONS PER TRACK.
C
C     SET MEASUREMENT MATRIX  Z  TO ZERO.
C
```

```
      DO 44 JZ=1,100
      DO 44 KZ=1,5
   44 Z(JZ,KZ) = 0.0
      AVEVA = 0.
      VARVA = 0.
C     WRITE (6,1092)
      COVXX = 0.0
      COVXY = 0.0
      COVYY = 0.0
C    Z(X,2) = FREQ INFO
C
      READ (5,56) (Z(J,2),J=1,NUM)
C     WRITE (6,58)
      WRITE (6,58)
58    FORMAT ('0INPUT FREQUENCY DATA')
C     WRITE (6,56) (Z(J,2),J=1,NUM)
      WRITE (6,56) (Z(J,2),J=1,NUM)
 56   FORMAT (6(F10.3))
C
C    Z(X,1) = BEARING INFO
C
      DO 9971 I=1,NUM
      ZHOLD(I)=Z(I,2)
9971  CONTINUE
      NUMZ=NUM
      DO 206 KIKM=1,3
      IF (KIKM.EQ.2) AVSK=4.5
      IF (KIKM.EQ.3) AVSK=7.0
      DO 201 JQ=1,JJQQ
      NUM=NUMZ
      DO 9972 I=1,NUMZ
      Z(I,2)=ZHOLD(I)
9972  CONTINUE
      IRE=0
      DATA F(1),F(2),F(3)/0.,0.,0./
C
C     WRITE(6,59)
C
C    SIMULATE BUOY MEASUREMENTS.
C
      DO 50 K=1,NUM
      CALL GAUSS(IXA,SA,AMA,VA)
      AVEVA = AVEVA + VA
      VARVA = VARVA + VA**2
      Z(K,1) = BR(1,K) + VA
   50 CONTINUE
C    ESTIMATE OF SOUND VELOCITY IS VP.
       VP=1625.5
```

```
C
C
C        KALMAN FILTER LINEAR STATES  USING  X,Y  COORDINATES
C      WITH NON - LINEAR MEASUREMENT MATRIX  AND STATE DEPENDENT
C     EXCITATION
C
C      CLEAR ALL MATRICES TO ZERO.
      DC 11 JJ=1,25
      CCV(JJ) = 0.
      CCVK(JJ) = 0.
      PHI(JJ) = 0.
      PHITR(JJ) = 0.
      QEXIT(JJ) = 0.
      RERROR(JJ) = 0.
      BERROR(JJ) = 0.
      TEMP4(JJ) = 0.
      TEMP5(JJ) = 0.
   11 CONTINUE
      DC 12 JJ=1,20
      GAIN(JJ) = 0.
      GAINTR(JJ) = 0.
      HOB(JJ) = 0.
      HOBTR(JJ) = 0.
      TEMP1(JJ) = 0.
      TEMP2(JJ) = 0.
      TEMP3(JJ) = 0.
   12 CONTINUE
C
C
      DO 92 I=1,16
   92 ZNOIS(I) = 0.
C
C     BEARING STANDARD DEVIATION IS SQ RT OF ZNOIS(1)  (IN RADIANS)
C
      ZNOIS(1) = (SA/57.29578)**2
C
C     FREQUENCY STANDARD DEVIATION IS SQ RT OF ZNOIS(4)
C
      ZNOIS(M+2) = SF**2
      ZNOIS(MM) = SF**2
      IF(M.EQ.4) ZNOIS(11) = ZNOIS(MM)
C
C
      WRITE(6,1058)
      LPB = 1
      DO 96 LP=1,M
      LPE = LP*M
C     WRITE(6,1059) (ZNOIS(KB),KB=LPB,LPE)
   96 LPB = LPE + 1
```

```
C
C        X(1) = X COORDINATE
C        X(2) = X VELOCITY
C        X(3) = Y COORDINATE
C        X(4) = Y VELOCITY
C        X(5) = REST FREQ,  FO.
C
C     ALL DIMENSIONS ARE GIVEN IN YARDS
C
C     1 KNOT  =  .563  YARDS / SEC.
C
C        MATRICES ARE STORED COLUMN BY COLUMN
C
C    TO WRITE OUT MATRICES ROW BY ROW THE TRANSPOSE MUST BE WRITTEN
C     SINCE THE STORAGE IN MEMMORY IS BY COLUMN
C
      AVS = AVSK*.563
C
C    CALCULATION OF THE INITAL CONDITIONS FOR THE FILTER.
C
C    TO INITIALIZE THE FILTER THE TWO BEARING MEASUREMENTS MUST
C      BE GREATER THAN 3 STD DEV OF THE NOISE APART.
C
      IABC=0
      KJ=1
   90 KJ = KJ + 1
      ADELTH = Z(KJ,1) - Z(1,1)
67    IF (KJ.EQ.(NUM+IABC)) GO TO 939
      IF (ABS(ADELTH).LT.(3.*SA)) GO TO 90
  939 CONTINUE
      ADELT = T(KJ) - T(1)
      ATHALF = (T(KJ) + T(1))/2.
      ADELF=Z(KJ,2) - Z(1,2)
      IF (ADELF.GE.0.0) GO TO 90
      AVKJ = T(KJ)/JJQQ + AVKJ
      ATHETH = 0.
C     WRITE(6,666) KJ,Z(KJ,1),Z(1,1),ADELTH
      DO 940 JA=1,KJ
  940 ATHETH = Z(JA,1)/KJ + ATHETH
C     WRITE(6,667) T(KJ),Z(KJ,2),Z(1,2),ADELF,ATHETH
      ATRUE = (((XS(KJ) + XS(1))/2.)**2 + ((YS(KJ) + YS(1))/2.)**2)**.5
   95 ASINE = -ADELF*VP/((ADELTH/57.29578)*Z(KJ,2)*AVS)
C     WRITE(6,668) ASINE
      IF(ABS(ASINE).LE.1.) GO TO 91
C
C    INITIAL SPEED ESTIMATE MUST BE TOO SLOW,  INCREASE BY 2 KNTS.
C
      AVS = AVS + 2.*.563
```

```
      GO TO 95
   91 HDT =(ARSIN(ASINE))*57.29578
      IF(Z(1,2).LE.FO) HDING =ATHETH + HDT
      IF(Z(1,2).GT.FO) HDING = 180. + ATHETH - HDT
      IF(HDING.GT.180.) HDING = HDING - 360.
      IF(HDING.LT.-180.) HDING = HDING + 360.
      HDDR = HDING/RAD
      AVTHR = ATHETH/RAD
      DELTHR = ADELTH/RAD
      ARHALF = RNG(AVS,DELTHR,HDDR,AVTHR)
      FO = Z(1,2)
C
C     ESTIMATE OF BEST FREQUENCY.
C
      FAVE = 0.
      DO 94 NJ=1,KJ
   94 FAVE = FAVE + Z(NJ,2)/KJ
      FO = FOIT(AVS,HDDR,AVTHR)
      IF(M.EQ.2) GO TO 944
C
C    ESTIMATION OF RANGE USING SECOND BUOY FREQ DATA.
C
      F2AVE = (Z(KJ,3) + Z(1,3))/2.
  941 COTEM = (VP/AVS)*(FO/F2AVE - 1.)
C
C    ADJUST FO IF ABS(COTEM) IS GREATER THAN 1.
C
      IF(COTEM.LT.-1.) FO = FO + .05
      IF(COTEM.GT.+1.) FO = FO - .05
      IF(ABS(COTEM).GT.1.) GO TO 941
      ANTEM = ARCOS(COTEM)*57.29578
C
C     TWO POSSIBLE BEARINGS TO THE SECOND BUOY.
C
      TH2(1) = HDING - ANTEM
      TH2(2) = HDING + ANTEM
      D2 = ((X(2) - X(1))**2 + (Y(2) - Y(1))**2)**.5
      T2 = ATAN((Y(2) - Y(1))/(X(2) - X(1)))*RAD
      IF((X(2) - X(1)).GE.0.) GO TO 942
      IF((Y(2) - Y(1)).LT.0.) T2 = T2 - 180.
      IF((Y(2) - Y(1)).GE.0.) T2 = T2 + 180.
  942 T1DF = (T2 - ATHETH)/RAD
      DO 943 KA=1,2
      T2DF =(T2 - TH2(KA))/RAD
      TDF = 1./TAN(T1DF) - 1./TAN(T2DF)
  943 ARX(KA) = D2/(SIN(T1DF)*TDF)
      IF(ABS(ARX(1) - ARHALF).LT.ABS(ARX(2) - ARHALF)) ARHALF = ARX(1)
      IF(ABS(ARX(2) - ARHALF).LT.ABS(ARX(1) - ARHALF)) ARHALF = ARX(2)
```

```
C
  944 CONTINUE
      XCUR(2) = AVS*COS(HDING/57.29578)
      XCUR(4) = AVS*SIN(HDING/57.29578)
      XCUR(1) = ARHALF*COS(ATHETH/57.29578)
      XCUR(3) = ARHALF*SIN(ATHETH/57.29578)
      XCUR(5) = FO
      XINT(1) = XCUR(1)
      YINT(1) = XCUR(3)
      XCUR(1) = XCUR(1)/1000.
      XCUR(3) = XCUR(3)/1000.
C     WRITE(6,708) XINT(1),YINT(1)
      XINT(2) = XINT(1) + XINT(2)
      YINT(2) = YINT(1) + YINT(2)
      XINVE = XINT(1)**2 + XINVE
      YINVE = YINT(1)**2 + YINVE
      OVX = VS*COS(THTAS)
      OVY = VS*SIN(THTAS)
C     WRITE(6,1100) ARHALF,ARTRUE,XCUR(2),OVX,XCUR(4),OVY
C     WRITE(6,1101) ATHALF,ATHETH,HDT,HDING,FO
      ARHALF = ARHALF/1000.
C
C    STANDARD DEVIATION OF INITIAL VELOCITY ASSUMED TO BE  3 KNOTS
C                     (1.7 YDS/SEC)
C
      ATHETH = ATHETH/RAD
      ADELTH = ADELTH/RAD
      ADELT = ADELT/1000.
      AK = FLOAT(KJ)
C
C     DIAGONAL INITIAL COVARIANCE IF M GE 3
      CCVK(1) = 4.0
      CCVK(7) = 2.0
      CCVK(13) =4.0
      CCVK(19) = 2.0
      CCVK(25) = 1.0
      IF(M.GE.3) GO TO 149
C             INITIAL COVARIANCE MATRIX
C
      CST = COS(ATHETH)
      SNT = SIN(ATHETH)
      FF = 1.4142*SF
      AA = 1.4142*SA/RAD
      VV = 3.*.563
      AVAV =(SA/SQRT(AK))/RAD
      HUF = HEAD(ADELF+FF,ADELTH,AVS,ATHETH)
      HDF = HEAD(ADELF-FF,ADELTH,AVS,ATHETH)
      HUA = HEAD(ADELF,ADELTH+AA,AVS,ATHETH)
```

```
      HDA = HEAD(ADELF,ADELTH-AA,AVS,ATHETH)
      HUV = HEAD(ADELF,ADELTH,AVS+VV,ATHETH)
      HDV = HEAD(ADELF,ADELTH,AVS-VV,ATHETH)
      XUF = RNG(AVS,ADELTH,HUF,ATHETH)*CST
      XDF = RNG(AVS,ADELTH,HDF,ATHETH)*CST
      SGXF = .5*(XUF -XDF)
      XUA = RNG(AVS,ADELTH+AA,HUA,ATHETH)*CST
      XDA = RNG(AVS,ADELTH-AA,HDA,ATHETH)*CST
      SGXA = .5*(XUA - XDA)
      XUV = RNG(AVS+VV,ADELTH,HUV,ATHETH)*CST
      XDV = RNG(AVS-VV,ADELTH,HDV,ATHETH)*CST
      SGXV = .5*(XUV - XDV)
      XUT = ARHALF*COS(ATHETH+AVAV)
      XDT = ARHALF*COS(ATHETH-AVAV)
      SGXT = .5*(XUT - XDT)
      SGYF = SGXF*SNT/CST
      SGYA = SGXA*SNT/CST
      SGYV = SGXV*SNT/CST
      YUT = ARHALF*SIN(ATHETH+AVAV)
      YDT = ARHALF*SIN(ATHETH-AVAV)
      SGYT = .5*(YUT -YDT)
      SGVXF = .5*AVS*(COS(HUF) - COS(HDF))
      SGVXA = .5*AVS*(COS(HUA) - COS(HDA))
      SGVXV = .5*((AVS+VV)*COS(HUV) - (AVS-VV)*COS(HDV))
      SGVYF = .5*AVS*(SIN(HUF) - SIN(HDF))
      SGVYA = .5*AVS*(SIN(HUA) - SIN(HDA))
      SGVYV = .5*((AVS+VV)*SIN(HUV) - (AVS-VV)*SIN(HDV))
      SGFF = .5*(FOIT(AVS,HUF,ATHETH) - FOIT(AVS,HDF,ATHETH))
      SGFA = .5*(FOIT(AVS,HUA,ATHETH) - FOIT(AVS,HDA,ATHETH))
      SGFV = .5*(FOIT(AVS+VV,HUV,ATHETH) - FOIT(AVS-VV,HDV,ATHETH))
      CCVK(1) = SGXF**2 + SGXA**2 + SGXV**2 + SGXT**2
      CCVK(7) = SGVXF**2 + SGVXA**2 + SGVXV**2
      CCVK(13) = SGYF**2 + SGYA**2 + SGYV**2 + SGYT**2
      CCVK(19) = SGVYF**2 + SGVYA**2 + SGVYV**2
      CCVK(25) = SGFF**2 + SGFA**2 + SGFV**2
C
C        SET NC = 1 IF ONLY DIAGONAL TERMS ARE WANTED
C
      NC = 0
      IF(NC.EQ.1) GO TO 149
C
      CCVK(2) = SGXF*SGVXF + SGXA*SGVXA + SGXV*SGVXV
      CCVK(3) = SGXF*SGYF + SGXA*SGYA + SGXV*SGYV + SGXT*SGYT
      CCVK(4) = SGXF*SGVYF + SGXA*SGVYA + SGXV*SGVYV
      CCVK(5) = SGXF*SGFF + SGXA*SGFA + SGXV*SGFV
      CCVK(6) = CCVK(2)
      CCVK(8) = SGVXF*SGYF + SGVXA*SGYA + SGVXV*SGYV
      CCVK(9) = SGVXF*SGVYF + SGVXA*SGVYA + SGVXV*SGVYV
```

```
      COVK(10) = SGVXF*SGFF + SGVXA*SGFA + SGVXV*SGFV
      COVK(11) = COVK(3)
      COVK(12) = COVK(8)
      COVK(14) = SGYF*SGVYF + SGYA*SGVYA + SGYV*SGVYV
      COVK(15) = SGYF*SGFF + SGYA*SGFA + SGYV*SGFV
      COVK(16) = COVK(4)
      COVK(17) = COVK(9)
      COVK(18) = COVK(14)
      COVK(20) = SGVYF*SGFF + SGVYA*SGFA + SGVYV*SGFV
      COVK(21) = COVK(5)
      COVK(22) = COVK(10)
      COVK(23) = COVK(15)
      COVK(24) = COVK(20)
C
  149 CONTINUE
C     WRITE(6,1061) COVK
C
C    PARAMETERS FOR EXCITATION MATRIX     SIGTH  -  HEADING STD DEV.
C                                         SIGVS  -  VELOCITY STD DEV.
C     COEF SQUARED FOR VARIANCE           SIGFO  -  REST FREQ STD DEV.
C
C    SIGTH = 10. DEGREES/100. SEC
      SIGTH = 3.04
C    SIGVS = 1 KNOT/100. SEC
      SIGVS = 31.7
C    SIGFO = .1 HZ/100. SEC
      SIGFO = 1.0
C
C
C     LOOP FOR MEASUREMENT DATA
C
C
      TT = (T(1) - ATHALF)/1000.
      DO 200 LL=1,NUM
      IF(LL.EQ.1) GO TO 88
      TT=(T(LL) - T(LL-1))/1000.
C
C     PUT IN PHI MATRIX
C
   88 PHI(1) = 1.
      PHI(7) = 1.
      PHI(13) = 1.
      PHI(19) = 1.
      PHI(25) = 1.
      PHI(6) = TT
      PHI(18) = TT
      CALL GMTRA(PHI,PHITR,5,5)
C     WRITE(6,1000) T(LL)
```

```
C
C     WRITE(6,1001) PHITR
C        XPRED=PHI*XCUR
      CALL GMPRD(PHI,XCUR,XPRED,5,5,1)
C
C     CALCULATE PREDICTED COVARIANCE MATRIX
C    NEED POSITIVE VALUES IN PHI MATRIX FOR COVARIANCE UPDATE.
      PHI(6) = ABS(TT)
      PHI(18) = ABS(TT)
      PHITR(2) = PHI(6)
      PHITR(14) = PHI(18)
C
C     CALCULATION OF THE STATE EXCITATION MATRIX.  IT IS STATE DEPENDENT.
C
      VSX = XCUR(2)**2 + XCUR(4)**2
      AX = (XCUR(2)**2/VSX)*SIGVS + (XCUR(4)**2)*SIGTH
      BX = XCUR(2)*XCUR(4)*(SIGVS/VSX - SIGTH)
      CX = (XCUR(4)**2/VSX)*SIGVS + (XCUR(2)**2)*SIGTH
      QEXIT(1) = AX*.25*TT**4
      QEXIT(2) = AX*.5*TT**3
      QEXIT(3) = BX*.25*TT**4
      QEXIT(4) = BX*.5*TT**3
      QEXIT(6) = QEXIT(2)
      QEXIT(7) = AX*TT*TT
      QEXIT(8) = QEXIT(4)
      QEXIT(9) = BX*TT*TT
      QEXIT(11) = QEXIT(3)
      QEXIT(12) = QEXIT(4)
      QEXIT(13) = CX*.25*TT**4
      QEXIT(14) = CX*.5*TT**3
      QEXIT(16) = QEXIT(4)
      QEXIT(17) = QEXIT(9)
      QEXIT(18) = QEXIT(14)
      QEXIT(19) = CX*TT*TT
      QEXIT(25) = SIGFO*TT*TT
C
C        COVK = PKK
C        COV = PKKM1
      CALL GMPRD(PHI,COVK,TEMP4,5,5,5)
      CALL GMPRD(TEMP4,PHITR,TEMP5,5,5,5)
      DO 7 JJ=1,25
    7 COV(JJ) = TEMP5(JJ) + QEXIT(JJ)
C     WRITE(6,1050) QEXIT
C     WRITE(6,1060) COV
C
C    LINEARIZED OBSERVATION MATRIX (TRANSPOSE)
C        HOBTR(1) - HOBTR(5)       ANGLE
C        HOBTR(6) - HOBTR(10)     FREQ(1)
```

```
C          HOBTR(11) - HOBTR(15)    FREQ(2)
C
C
C       PREDICTED BEARING IS H1.
C
      IF(XPRED(1).GT.0.) GO TO 9975
      IF (XPRED(3).GE.0.) H1=PI
      IF (XPRED(3).LT.0.) H1=-PI
      GO TO 45
9975  H1=ATAN(XPRED(3)/XPRED(1))
      IF(XPRED(1).GT.0.) GO TO 45
      IF(XPRED(3).GE.0.) H1 = H1 + 3.14159
      IF(XPRED(3).LT.0.) H1 = H1 - 3.14159
   45 CONTINUE
C
      DO 46 N=1,M1
      NN = 5*N
      XDIS = XPRED(1) - X(N)/1000.
      YDIS = XPRED(3) - Y(N)/1000.
      XYSQ(N) = XDIS**2 + YDIS**2
      F(N) = XPRED(5)*VP/(VP +((XPRED(2)*XDIS + XPRED(4)*YDIS)/(XYSQ(N)*
     1*.5)))
      A = -(F(N)**2)/(XPRED(5)*VP)
      HOBTR(NN+1)= (A*YDIS*(YDIS*XPRED(2) - XDIS*XPRED(4)))/XYSQ(N)**1.5
      HOBTR(NN+2)= (A*XDIS)/XYSQ(N)**.5
      HOBTR(NN+3)=-HOBTR(NN+1)*XDIS/YDIS
      HOBTR(NN+4)= HOBTR(NN+2)*YDIS/XDIS
      HOBTR(NN+5) = F(N)/XPRED(5)
   46 CONTINUE
      HOBTR(1) = -XPRED(3)/XYSQ(1)
      HOBTR(2) = 0.
      HOBTR(3) = XPRED(1)/XYSQ(1)
      HOBTR(4) = 0.
      HOBTR(5) = 0.
      CALL GMTRA (HOBTR,HOB,5,M)
C     WRITE(6,1020)(HOBTR(K),K=1,M2)
C
C    CALCULATE THE GAIN MATRIX
C
      CALL GMPRD(COV,HOBTR,TEMP1,5,5,M)
      CALL GMPRD(HOB,TEMP1,TEMP2,M,5,M)
      DO 22 JJ=1,MM
   22 TEMP2(JJ) = TEMP2(JJ) + ZNOIS(JJ)
      CALL MINV(TEMP2,M,D,LT,WM)
C     WRITE(6,9010) D
      CALL GMPRD(TEMP1,TEMP2,GAIN,5,M,M)
      GA(LL)=GAIN(1)
      CALL GMTRA(GAIN,GAINTR,5,M)
```

```
C     WRITE (6,1039)
      IB = 1
      DO 47 I=1,5
      IE = M*I
C     WRITE(6,1040) (GAINTR(MG),MG=IB,IE)
   47 IB = IE + 1
C
C    UPDATE THE COVARIANCE MATRIX
C
      CALL GMPRD(GAIN,HOB,TEMP4,5,M,5)
      DO 3 JJ=1,25
    3 TEMP4(JJ) = -TEMP4(JJ)
      DO 444 JJ=1,25,6
  444 TEMP4(JJ) = 1. + TEMP4(JJ)
      CALL GMPRD(TEMP4,COV,COVK,5,5,5)
C     WRITE(6,1070) COVK
C
C   CALCULATE RESIDUAL BASED ON ESTIMATED VALUE OF THE OBSERVATIONS
C     AND THE INPUT MEASUREMENT
C
      HH1 = H1*57.29578
      RESA = Z(LL,1) - HH1
      IF(RESA.LT.-180.) RESA = RESA + 360.
      IF(RESA.GT. 180.) RESA = RESA - 360.
      RESF1 = Z(LL,2) -F(1)
      IF(RESA.GT.2.*SA) IRE = IRE + 1
      IF(RESF1.GT.4.*SF) IRE = IRE+ 1
      RESF2 = Z(LL,3) - F(2)
      RESF3 = Z(LL,4) - F(3)
C     WRITE(6,2010) (Z(LL,J),J=1,M)
C     WRITE(6,2000) HH1,(F(J),J=1,M1)
      IF(M.LE.3) RESF3 = 0.
      IF(M.EQ.2) RESF2 = 0.
C     WRITE(6,2011) RESA,RESF1,RESF2,RESF3
C
      RESA = RESA/57.29578
      DO 6 J=1,5
      XFIL(J) =XPRED(J)+GAIN(J)*RESA + GAIN(J+5)*RESF1+GAIN(J+10)*RESF2
     1 + GAIN(J+15)*RESF3
      XFIL(5) = XFIL(5) - FREQ
      XMC(J,LL) = XFIL(J) + XMC(J,LL)
      XVAR(J,LL) = XFIL(J)**2 + XVAR(J,LL)
    6 CONTINUE
      XFIL(5) = XFIL(5) + FREQ
      XYVAR(1,LL) = XFIL(1)*XFIL(3) + XYVAR(1,LL)
      XYVAR(2,LL) = XFIL(2)*XFIL(4) + XYVAR(2,LL)
      XTAR(LL) = XFIL(1)*1000.
      YTAR(LL) = XFIL(3)*1000.
```

```
      BTEMP = (ATAN(XFIL(3)/XFIL(1)))*57.29578
      IF(XFIL(1).GT.0.) GO TO 49
      IF(XFIL(3).GE.0.) BTEMP = BTEMP + 180.
      IF(XFIL(3).LT.0.) BTEMP = BTEMP - 180.
   49 CONTINUE
      RTEMP = (XFIL(1)**2 + XFIL(3)**2)**.5
      RTEMP = RTEMP*1000.
      RERROR(LL) =((XS(LL) -XFIL(1))**2 + (YS(LL) -XFIL(3))**2)**.5
      BERROR(LL) = BR(1,LL) - BTEMP
      VSFIL = (XFIL(2)**2 + XFIL(4)**2)**.5
      VSFIL = VSFIL/.563
      HDFIL = ATAN(XFIL(4)/XFIL(2))*57.29578
      IF(XFIL(2).GT.0.) GO TO 48
      IF(XFIL(4).GE.0.) HDFIL = HDFIL + 180.
      IF(XFIL(4).LT.0.) HDFIL = HDFIL - 180.
   48 CONTINUE
C     WRITE(6,1080) XCUR,XPRED,XFIL
      XSL = XS(LL)/1000.
      YSL = YS(LL)/1000.
C     WRITE(6,1081) XSL,OVX,YSL,OVY,FREQ
C     WRITE(6,1082) VSFIL,HDFIL
C     WRITE (6,1094) LL
1094  FORMAT (I6)
C     WRITE(6,1091) RTEMP,BTEMP,R(1,LL),BR(1,LL)
      DO 199 KK=1,5
  199 XCUR(KK) = XFIL(KK)
  200 CONTINUE
      COVXX = COVK(1)/JJQQ + COVXX
      COVXY = COVK(3)/JJQQ + COVXY
      COVYY = COVK(13)/JJQQ + COVYY
C     WRITE (6,57)
57    FORMAT('1PLOT OF GAIN(1) VRS TIME POINTS')
C     CALL PLOTP (T,GA,NUMZ,0)
C     WRITE(6,1093) XFIL,IRE
C     WRITE(6,330)
C     CALL PLOTP(X,Y,-5,1)
C     CALL PLOTP(XINT,YINT,2,2)
C     CALL PLOTP(XS,YS,NUM,2)
C     CALL PLOTP(XTAR,YTAR,NUM,3)
  201 CONTINUE
      DO 203 LL=1,NUM
      DO 202 J=1,5
      XMC(J,LL) = XMC(J,LL)/JJQQ
202   CONTINUE
      XMC(5,LL) = XMC(5,LL) + FREQ
      XMN(LL) = XMC(1,LL)*1000.
  203 YMN(LL) = XMC(3,LL)*1000.
      WRITE(6,700) JJQQ
```

```
      WRITE (6,9977) FC,AVSK,SF,SA
9977  FORMAT ('0FC=',F6.1,2X,'AVSK=',F4.1,2X,'SF=',F6.3,
     .2X,'SA=',F5.1)
C
      XINT(1) = 0.
      YINT(1) = 0.
      XINT(2) = XINT(2)/JJQQ
      YINT(2) = YINT(2)/JJQQ
      CALL PLOTP(X,Y,5,1)
      CALL PLOTP(XINT,YINT,2,2)
      CALL PLOTP (XS,YS,NUMZ,2)
      CALL PLOTP(XMN,YMN,NUM,3)
  204 CONTINUE
206   CONTINUE
      END
      FUNCTION HEAD(DF,DT,VS,AV)
   10 FORMAT('0  ASINE',F15.4)
 8001 FORMAT('0',9F12.6)
      COMMON FQ,VP,FO,PI,RAD
C     WRITE(6,8001) DF,DT,VS,AV,FQ,VP,FC,PI,RAD
      ASINE = -VP*DF/(FQ*DT*VS)
C     WRITE(6,10) ASINE
      IF(ASINE.GT.1.) ASINE = 1.
      IF(ASINE.LT.-1.) ASINE = -1.
      H = PI + AV - ARSIN(ASINE)
      IF(FQ.LT.FO) H = AV + ARSIN(ASINE)
      IF(H.GT.PI) H = H - 2.*PI
      IF(H.LT.-PI) H = H + 2.*PI
      HEAD = H
      RETURN
      END
```

BIBLIOGRAPHY

1. Mitschang, G. W., An Application of Nonlinear Filtering Theory to Passive Target Location and Tracking, Ph. D. Thesis, Naval Postgraduate School, June 1974.

2. Coppens, A. B., Sound in the Ocean, unpublished notes presented in PH3452, p. 1, Naval Postgraduate School, November 1973.

3. Arfman, J. F., Jr., A Software Package for Analysis of Geophysical Measurements, M.S. Thesis, Naval Postgraduate School, June 1971.

4. Urick, R. J., Principals of Underwater Sound for Engineers, pp. 264-266, McGraw-Hill, 1967.

5. Coppens, A. B., The Sonar Equations, unpublished notes presented in PH3452, p. 14, Naval Postgraduate School, November 1973.

6. Singleton, R. C., "An Algorithm for Computing the Mixed Radix Fast Fourier Transform," Transactions on Audio and Electroacoustics, V. AU-17, No. 2, pp. 93-103, June 1969.

INITIAL DISTRIBUTION LIST

		No. Copies
1.	Defense Documentation Center Cameron Station Alexandria, Virginia 22314	2
2.	Library, Code 0212 Naval Postgraduate School Monterey, California 93940	2
3.	Department Chairman, Code 52 Department of Electrical Engineering Naval Postgraduate School Monterey, California 93940	2
4.	Professor H. A. Titus, Code 52Ts Department of Electrical Engineering Naval Postgraduate School Monterey, California 93940	10
5.	Naval Security Group Command Attn: G80 3801 Nebraska Ave. Washington, D.C. 20390	2
6.	Asst. Professor D. E. Kirk, Code 52Ki Department of Electrical Engineering Naval Postgraduate School Monterey, California 93940	1
7.	Asst. Professor J. E. Ohlson, Code 5201 Department of Electrical Engineering Naval Postgraduate School Monterey, California 93940	1
8.	Naval Security Group Command Attn: LT George W. Mitschang, USN 1301 Nebraska Ave. Washington, D.C. 20390	1
9.	Staff, Commander Patrol Wings U. S. Atlantic Fleet Attn: LT Dennis W. Hurst, USN Naval Air Station Brunswick, ME. 04011	1

Thesis 153874
H9573 Hurst
c.1
Automatic frequency tracking and an application of target tracking using passive doppler techniques.